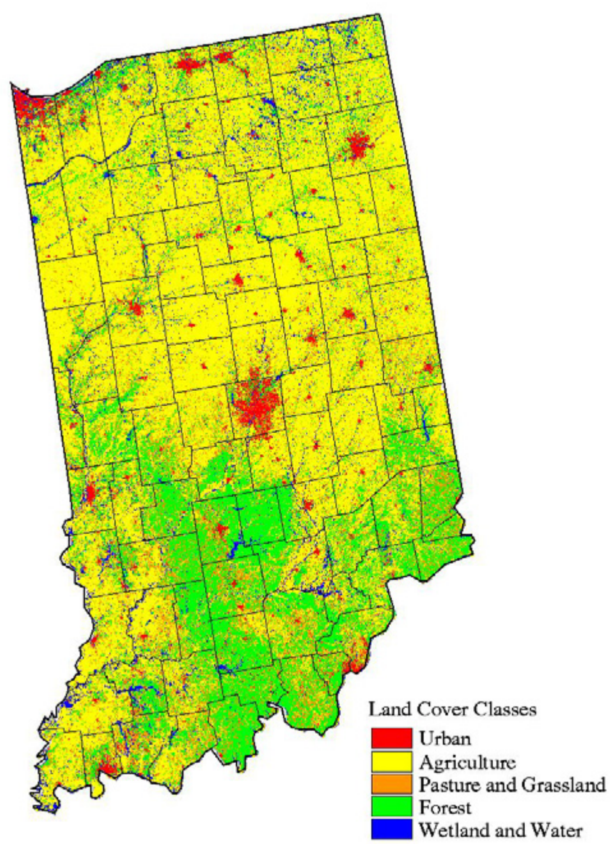
Quantifying the Change in Greenhouse Gas Emissions due to Natural Resource Conservation Practice Application in Indiana

“The Indiana Carbon Storage Project”



Report to the Indiana Conservation Partnership February, 2002

A collaborative effort between USDA Natural Resources Conservation Service and Colorado State University - Natural Resource Ecology Laboratory, Fort Collins, CO

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Project

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Project Authority

Interagency Agreement between the U.S. Department of Energy (DOE) and the U.S. Department of Agriculture-Natural Resources Conservation Service (NRCS).

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Executive Summary

Land managers have long known the importance of soil organic matter in maintaining the productivity and sustainability of agricultural land. More recently, interest has developed in the potential for using agricultural soils to sequester C and mitigate increasing atmospheric CO_2 by adopting practices that increase standing stocks of carbon in soil organic matter and vegetation. Practices that increase the amount of CO_2 taken up by plants (through photosynthesis), which then enter the soil as plant residues, tend to increase soil C stocks. Likewise, management practices that reduce the rate of decay or "turnover" of organic matter in soils will also tend to increase carbon stocks.

In 1999, we initiated a state-wide assessment of how management decisions involving cropping and tillage systems affect soil organic matter. Our approach utilized a variety of resource data (on climate, soils, land use and management), long-term field experiment results, and the Century EcoSystem Soil Organic Matter Computer Model. An initial Phase I study of cropland in Indiana utilized existing information on climate, soils and management factors (e.g., drainage, crops grown, production levels and tillage systems) and estimated Indiana to be a slight source of 0.12 million metric tonnes per year (MMT) of C to the atmosphere. From this Phase I study, it was apparent that the individual counties had land use information, including management histories of cropping rotations, drainage histories, fertilizer rates, and conservation practices that were not available in published databases. It was also ascertained from the Phase 1 study that local land managers wanted additional information about C sequestration, and local conservation districts were willing to report any C sequestered due to conservation practices to the US Department of Energy (DOE).

The Phase II study was started in 1999 and involved all 92 counties. This general approach of involving every county within a state had recently been successfully used in a similar study in Iowa. For the project to be successful, it was necessary to devise a means of improving communication with the local land managers and collecting the local data. The Carbon Sequestration Rural Appraisal (CSRA) survey instrument was modified, tested and implemented in each county using an electronic spreadsheet format. Individually tailored spreadsheets were prepared for each county and electronically transmitted to Indiana. Local data only available at the county level was filled in each spreadsheet. All spreadsheets were electronically transmitted back to Fort Collins, CO when completed. This local data provided

additional inputs into the Century Model that were not available in previously published databases, and refined the output for the individual counties and the soils and crop/tillage systems within each county. Century estimates for over 800,000 different scenarios showing the C changes are now available in the Indiana CarbOn Management Evaluation Tool (COMET) database. The county summaries for the amounts of C sequestered in 1990-1999 are also available.

The Phase II assessment for Indiana suggests that agricultural soils are currently (based on 1999 data) sequestering 0.77 MMT of carbon per year (equivalent to 2.8 MMT of CO_2 per year), largely through increased adoption of conservation practices over the past 10 to 20 years. Mineral soils are estimated to be sequestering 1.46 MMT of C per year (5.4 MMT of CO_2), but the cultivation of organic soils are a source of 0.68 MMT of C (2.5 MMT of CO_2) back to the atmosphere. Excluding the impact from the cultivation of organic soils, sound conservation practices on Indiana cropland is sequestering C and is equivalent to an offset of 2.7% of Indiana's 1999 fossil fuel carbon emissions.

Background

During the last century, human activities, such as burning fossil fuels, have dramatically increased the concentration of greenhouse gases (GHGs) in the atmosphere. GHGs trap heat inside the atmosphere much like the way glass traps heat inside a greenhouse (Figure 1). Without these gases, the earth would be too cold for human habitation (U.S. Global Change Research Program, 2000). However, the effects of the human-induced increase in GHG concentrations are uncertain. Many scientists believe that increased atmospheric GHGs will result in unpredictable and potentially severe changes to the Earth's climate with unknown impacts on weather patterns, sea levels, cropland production, and national economies (IPCC, 1996).

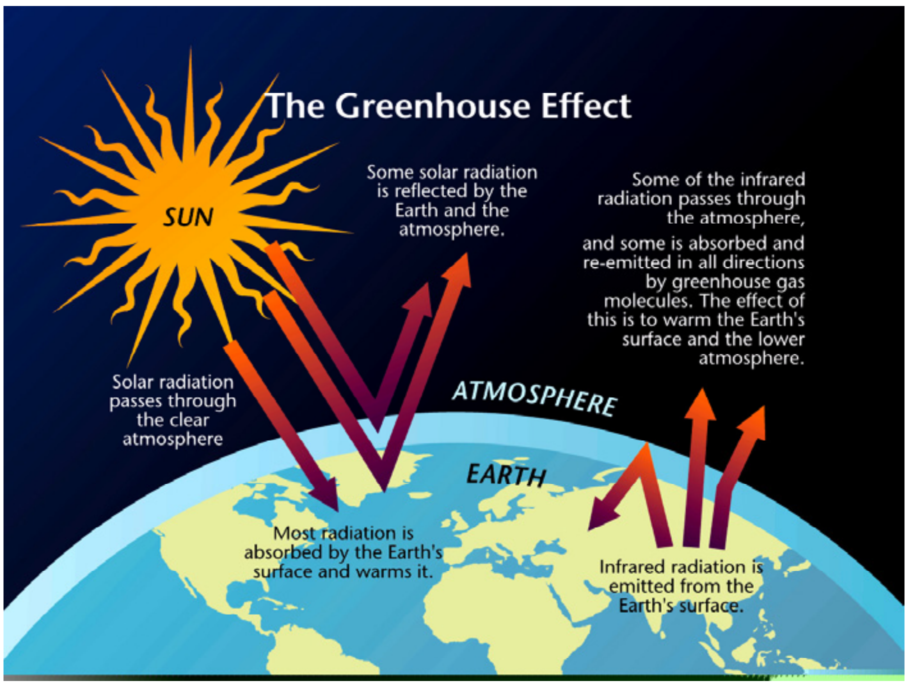


Figure 1: The greenhouse effect

GHGs are produced naturally in the environment and have resided in the atmosphere since well before the age of industrialization when humans began to contribute additional amounts to the atmosphere. Three GHGs that are of primary concern include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). This study concentrates on CO_2, which is the most prevalent GHG in terms of quantity in the atmosphere and has the greatest overall effect on warming. However, on a molecule-for-molecule basis, N_2O has the greatest warming potential, followed by CH_4 and then CO_2. CO_2 levels have risen substantially over the past century as evidenced by the long-term record of ice cores and atmospheric measurements shown in Figure 2 (Neftel et al., 1994; Keeling, et al., 2000).

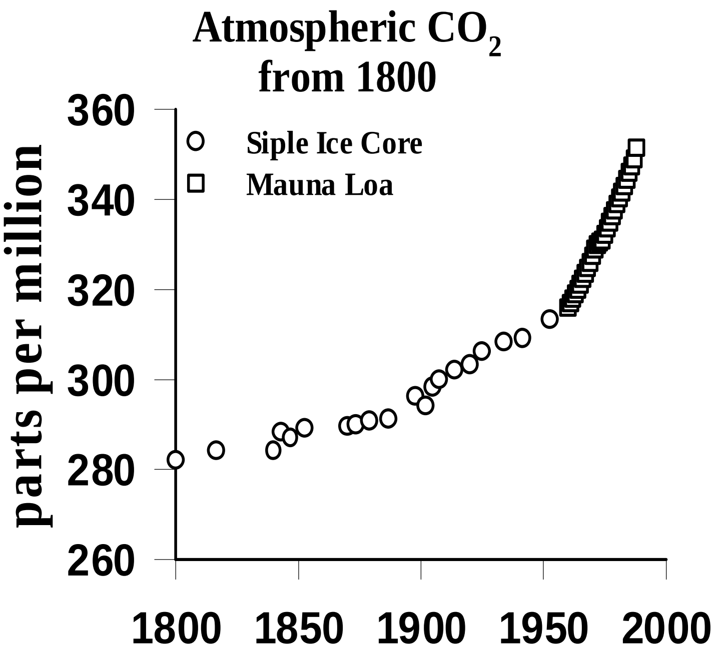


Figure 2: Atmospheric CO_2 from 1800-present

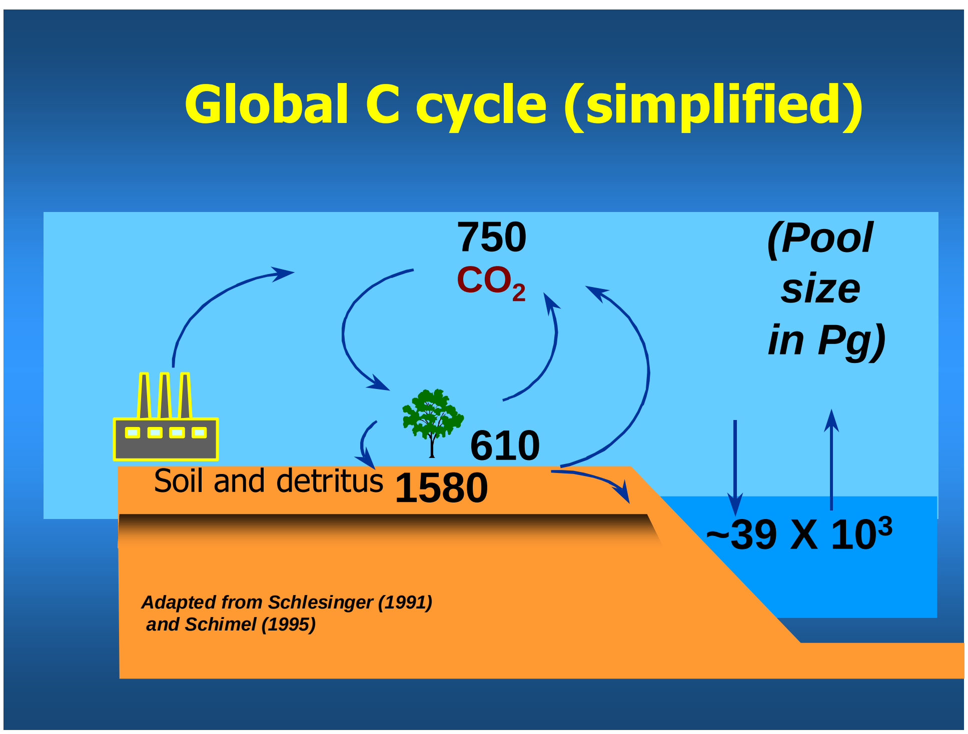


Figure 3: The global C cycle

The continual cycling of carbon through the earth's atmosphere and terrestrial biota make up an important part of the global carbon cycle (Figure 3, Schlesinger, 1991; Schimel, 1995). CO_2 is released into the atmosphere as a product of respiration, the process used by plants, animals, and microorganisms to gain energy for bodily functions. Humans, through industrial activities, have added CO_2 to the atmosphere due to the burning of fossil fuels (coal, natural gas, and oil). CO_2 is removed from the atmosphere during photosynthesis when plants convert it into biomass, including leaves, branches, stems, and roots. This biomass carbon will eventually be returned to the atmosphere upon the death and decomposition of the organism. In the interim, it is sequestered or retained on the land as dead plant and animal material that is broken down by microorganisms and incorporated into the soil. Carbon can remain in soils for thousands of years, effectively storing or sequestering CO_2 from the atmosphere (Figure 4).

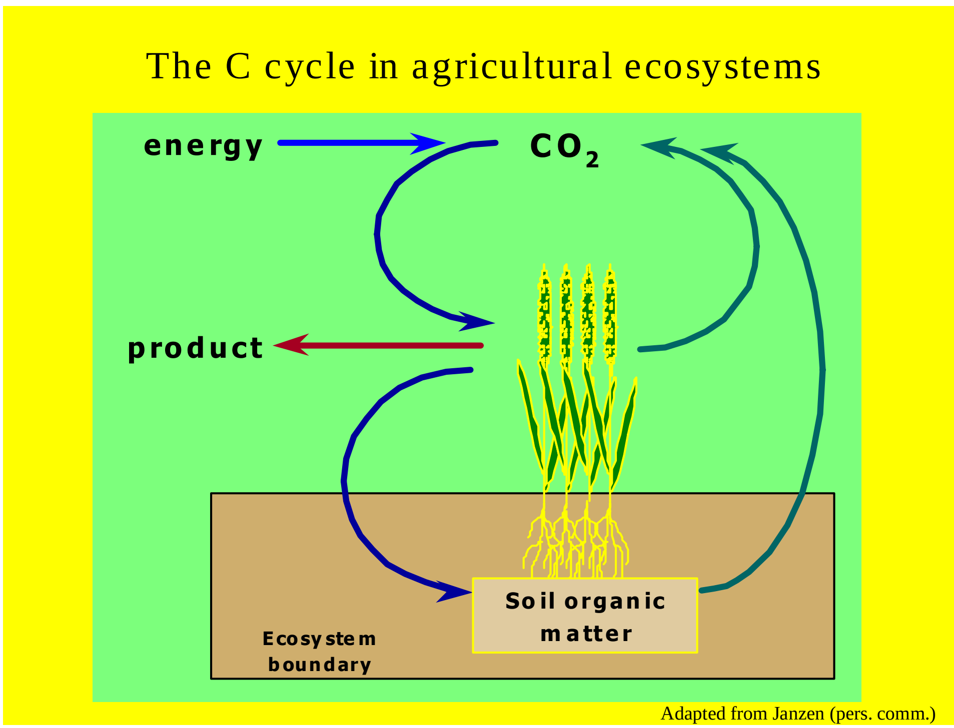


Figure 4: C cycle in agricultural ecosystems

Agricultural soils contain substantial amounts of carbon, typically 20 to 80 tonnes per hectare in the top 20 cm. However, relative to their native ecosystem levels, most agricultural soils are depleted in carbon, having lost 30-50% of their original carbon levels due to changes associated with production agriculture and past management practices (Figure 5). Historically, agricultural practices often resulted in reduced inputs of carbon through plant residues and increased losses via decomposition and erosion (Paustian et al. 1997a). Lower productivity,

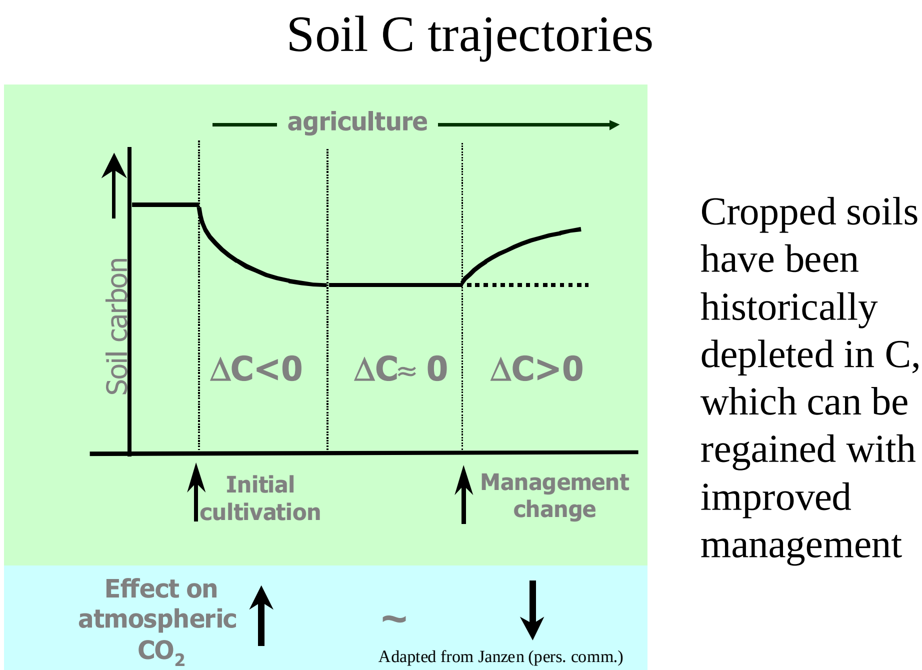


Figure 5: Soil C trajectories

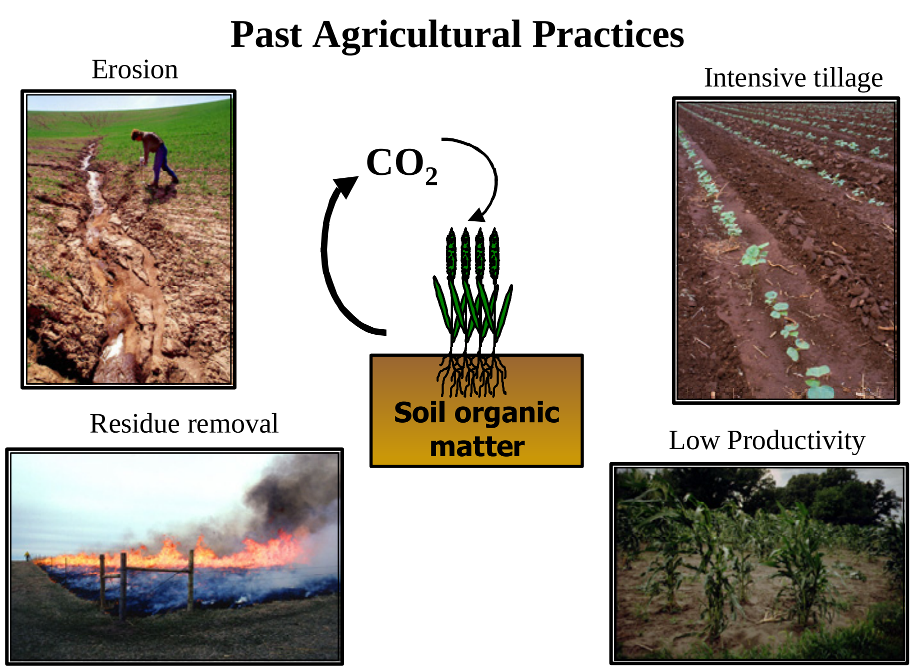


Figure 6: Past agriculture practices

particularly prior to the 1950s, and greater removal of crop residues decreased the amount of plant material that could potentially add carbon to the soil (Figure 6). More intensive tillage, allowing microorganisms to break down more organic matter and encouraging soil erosion, increased losses of soil carbon.

Through improved agricultural practices, farmers can increase carbon storage in soils (Paustian et al., 1997a, 1998, 2000; Lal et al., 1998). Conservation tillage (e.g., no-till or reduced till) helps protect soil carbon from microbial attack by preserving a more stable aggregate structure and also helps to decrease soil erosion. Better residue management enhances carbon input to soil by leaving more plant material in the fields for conversion to soil organic matter. Improved cropping rotations can also enhance soil productivity by increasing the amount of plant material that becomes soil organic matter. Winter cover crops add additional residues to the soil and help decrease soil erosion and nitrogen losses. An effective option for increasing carbon storage in the soil is to set aside land in long-term, permanent cover, such as the Conservation Reserve Program (CRP) as well as in conservation buffers (e.g. filter strips, grassed waterways). This leads to higher amounts of soil organic matter because there is reduced soil disturbance and more plant material incorporated into the soil by the perennial biomass (Figure 7).

The United States is involved, both nationally and internationally, in efforts to stabilize atmospheric GHG concentrations at a level that would prevent dangerous interference with the Earth's climate. Title XVI of the Energy Policy Act of 1992 addresses global climate change, and Section 1605(b) specifically mandates the development of procedures for the voluntary reporting of GHG emission reductions. Agriculture has shown that the voluntary application of conservation practices can provide sustainability and protection of natural resources.

Over the last 60 years, the NRCS, working through 3,000 local conservation districts, have provided technical assistance and funding to farmers who implement soil and water conservation practices. Many of these practices utilize permanent vegetation and crop residues to increase soil organic matter, which are also providing a benefit of removing CO_2 from the atmosphere and sequestering C in the soil. These management practices have been implemented according to NRCS standards and specifications, and are recorded in conservation district records as verifiable documentation of their existence and location.

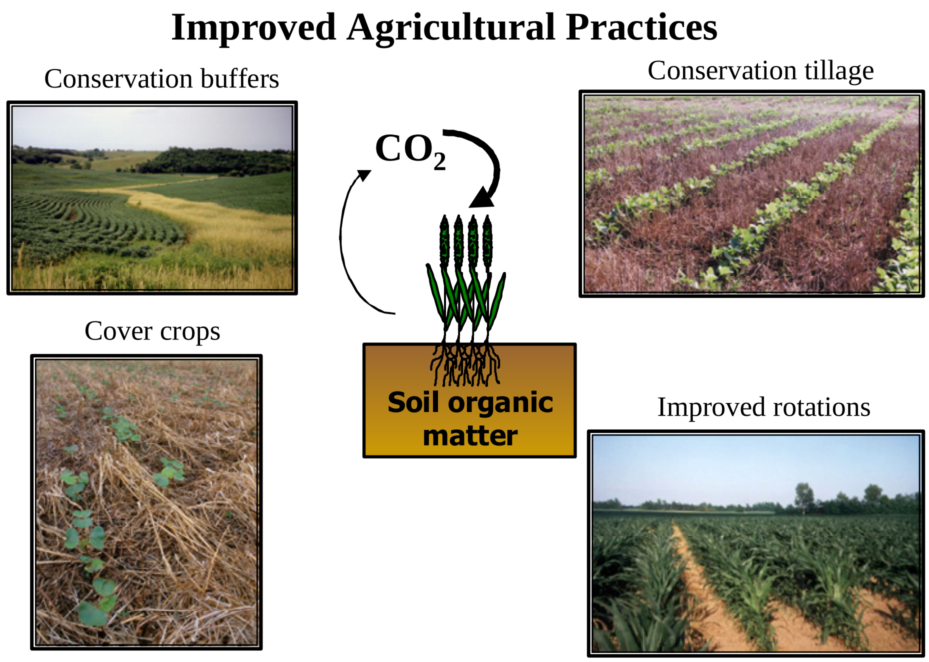


Figure 7: Improved agricultural practices

Objectives And Outcomes

The growing recognition that human-induced increases in the concentrations of greenhouse constitutes a serious environmental threat – together with the realization that agriculture can play a significant role in mitigating this threat – has stimulated interest, both in the private and the public sector, in pursuing agriculturally-based mitigation strategies. To develop and implement effective mitigation programs, quantification and assessment capabilities are needed.

Our objectives were

I) to provide an assessment of current rates of carbon sequestration on a state-wide basis in Indiana,

II) to assess the potential for increased carbon sequestration with wider adoption of conservation practices and

III) to provide locally-relevant estimates and decision tools for evaluating alternative management strategies with respect to their potential to sequester carbon in soils.

The analysis was designed to account for the complex interactions of varying climate, soil and management conditions across the State, both to increase the accuracy of the total estimates for the state as well as to provide locally-relevant information for managers and decision-makers in individual counties/conservation districts. The assessment was initiated using existing information compiled by USDA/NRCS and other sources, together with a state-of-the-art simulation model capable of integrating climate and soil conditions, land use change and agricultural management practices and their effects on soil carbon changes over time. The Century model, developed by the Natural Resource Ecology Laboratory/Colorado State University and USDA/ARS, was chosen, based on its ability to incorporate effects of historical land use and a wide variety of management practices as well as its wide-spread use and recognition in the US and internationally.

Following an initial project phase utilizing existing information on land use and management practices, the project was expanded to include acquisition and use of locally derived information, through the development of a survey instrument called the Carbon Sequestration Rural Appraisal (CSRA). The objectives of the CSRA were to provide local input about current and historical management practices for use in the modeling and at the same time to provide training and information about greenhouse gas mitigation and carbon sequestration.

Products of the research include state-wide estimates of carbon sequestration, broken out for various land use and management practices and displayed by maps and county-level tables to show spatial distributions across the state. COMET (CarbOn Management Evaluation Tool) database, which can be queried by specific soils, historical land use, and management combinations, for each county in the state, provides a means for local Soil and Water Conservation Districts to estimate the effects of current management systems on carbon sequestration and to make projections of carbon sequestration through changes in management and the adoption of conservation practices. NRCS offices will be able to use this database to assist them in the planning process and provide assistance on best management practices as well as other local agricultural producers, policy makers and business interests. Estimates of current soil carbon sequestration for each conservation district have been submitted to DOE as part of a program on voluntary greenhouse gas mitigation reporting. Finally results of the project have been presented at numerous scientific and public meetings, scientific publications, trade journals and newspaper articles and has led to the initiation of similar projects in other states.

Assessment Procedure

Our approach combines data and modeling within an overall framework designed for quantifying regional ecosystem properties and dynamics (Figure 8). Here we briefly describe this framework, which is discussed in more detail in Paustian et al. (1995), Elliott and Cole (1989) and Brenner et al. (2001).

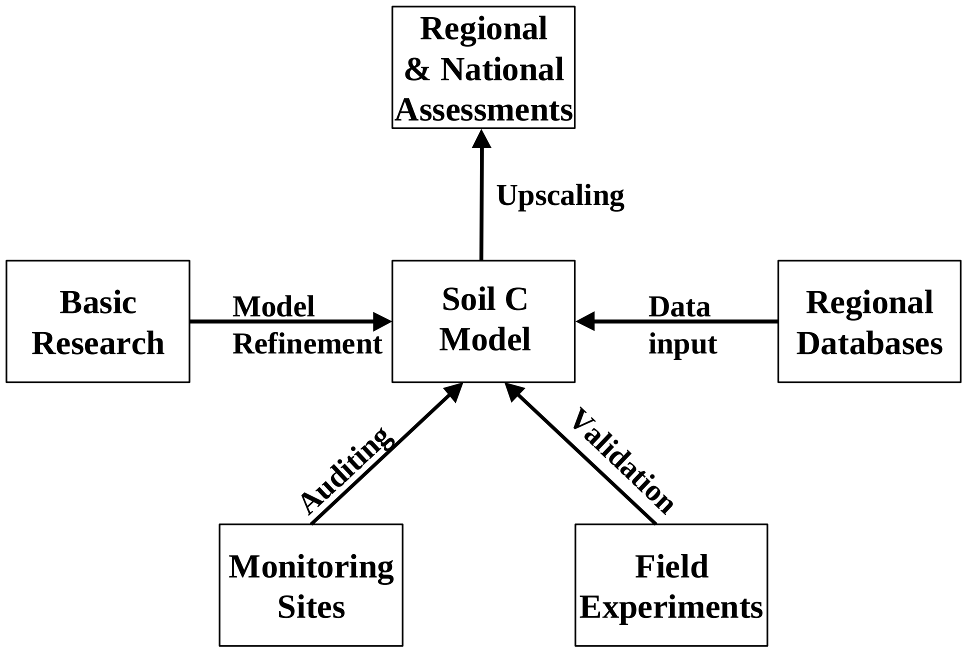


Figure 8: Framework for ecosystem modeling

The overall integration is provided by a simulation model, which is based on extensive basic research on ecosystem carbon and nutrient dynamics. The model utilizes spatial databases of driving variables (i.e. climate, soil properties, management factors) to calculate soil C changes for combinations of these driving variables, allowing the results to be combined and scaled up to the county and state levels. Data from long-term experiments, spanning a similar range of climate, soil and management, are used to test and validate model performance across the range of conditions in the region. The establishment of on-farm monitoring or 'benchmark' sites provides additional field-based verification, under actual farm conditions, of soil C changes due to management. A monitoring system, however, has not been established at this time in Indiana and was not a component of this study.

Modeling Soil Organic Matter

The Century EcoSystem Soil Organic Matter Computer Model used in this study was first developed for grassland systems (Parton et al., 1987, 1988) but has subsequently been updated and enhanced (Metherall, et al., 1993; Paustian et al., In prep.) and has been used extensively to simulate organic matter and nutrient dynamics in agricultural cropping systems (e.g., Paustian et al., 1992, 1996, 2001; Carter et al., 1993; Parton and Rasmussen, 1994). Century simulates long-term dynamics of carbon, nitrogen, phosphorus and sulfur in the top 20 cm of soil on a monthly basis and has proven to provide reliable estimates of soil C changes. Soil organic carbon and nitrogen stocks are represented by two plant litter pools and three soil organic matter pools (termed active, slow, and passive). The crop growth submodel simulates crop growth, dry matter production and yield to estimate the amount and quality of residue returned to the soil, as well as plant influence on soil water, nutrients and other factors affecting soil organic matter turnover. The soil water balance submodel calculates water balance components and changes in soil water availability, which influence both plant growth and decomposition/nutrient cycling processes. A variety of management options may be specified including crop type, tillage, fertilization, organic matter addition (e.g., manuring), harvest (with variable residue removal), drainage, irrigation, burning and grazing intensity. Specifying crop type and management options in the management schedule file simulates the desired cropping sequence. Figure 9 provides an overview of the Century model illustrating the main components of the model. Only carbon and nitrogen dynamics were addressed in this research. Model simulations did not include the occurrence of soil erosion.

To evaluate the model under conditions representative for the Corn Belt Region of the U.S., the model was used to simulate long-term continuous corn and corn-soybean cropping systems at five different locations involving various soil types and climate regimes, involving a total of 29 separate treatments for tillage and fertilization management (Paul et al., 1997) (Lafayette, IN; Lexington, KY; Hoytville, OH; Wooster, OH; and Arlington, WI). To test the model's ability to estimate soil carbon levels and changes due to management without using site-specific information on initial soil C levels, we initialized and executed the model using only climate, soil physical properties, and management driving variables. The model first estimated pre-cultivation soil carbon contents under native vegetation using a stochastic weather generator (based on long-term mean climate) and the physical description for the site, including soil texture

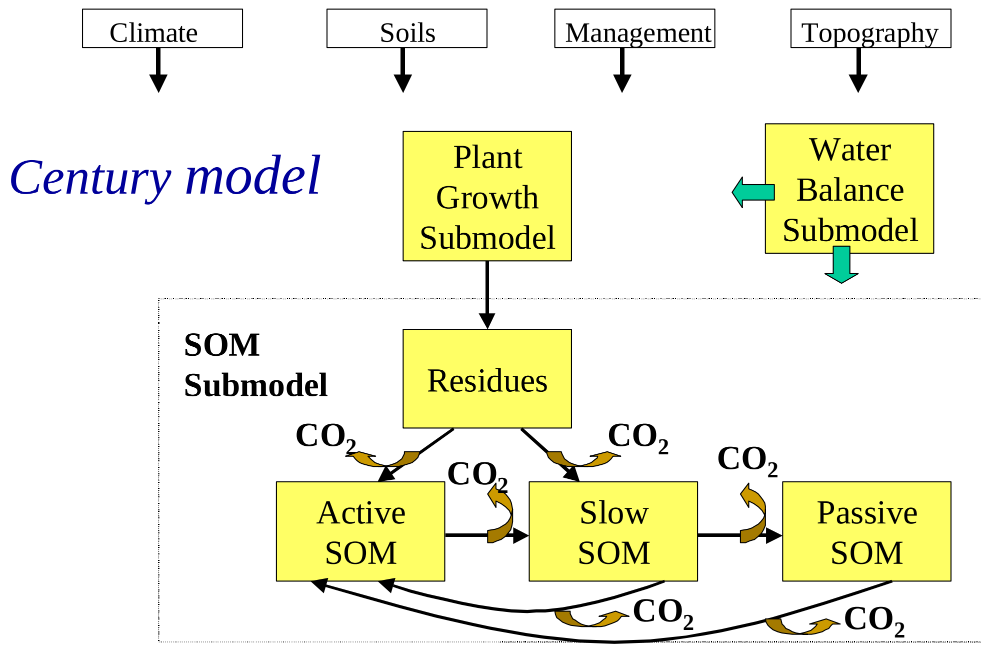


Figure 9: Century model

and soil hydric properties. We assumed the vegetation to be tall grass prairie, which was moderately grazed in the summer months with a fire frequency of three years, and the model was run for 6000 years to approximate steady-state conditions. Next, representative historical practices, as reported by the managers of each of the long-term sites and/or based on published literature, were simulated for the period from initial cultivation (mid to late 1800s) to the start of the field experiment. Observed weather data from the nearest weather station were used for the period of record. Finally, the field experimental period was simulated using the actual management practices for multiple treatments per site, as reported by the site managers (Paul et al., 1997). Most of the experiments have been in place for 20-30 years. Model simulations were run based on these data and compared to measured soil C and crop yields reported for each site. The model explained 85% of the variability across all treatments, sites, and time periods, using all published data from the studies and explained 82% of the variability when looking at only soil C data obtained in 1992 from a cross-site sampling which we conducted (Figures 10 and 11). Comparison of measured and modeled values did not reveal any systematic biases (e.g., associated with particular soil types or management factors) and gives confidence in the generality of the model and it's ability to estimate soil C changes for a range of conditions across the Corn Belt, using a uniform parameterization. For the Phase I and Phase II analysis, we initialized the model in a similar fashion as described above, by first estimating pre-cultivation soil C contents followed by changes due to historical cropping practices up to and including present conditions.

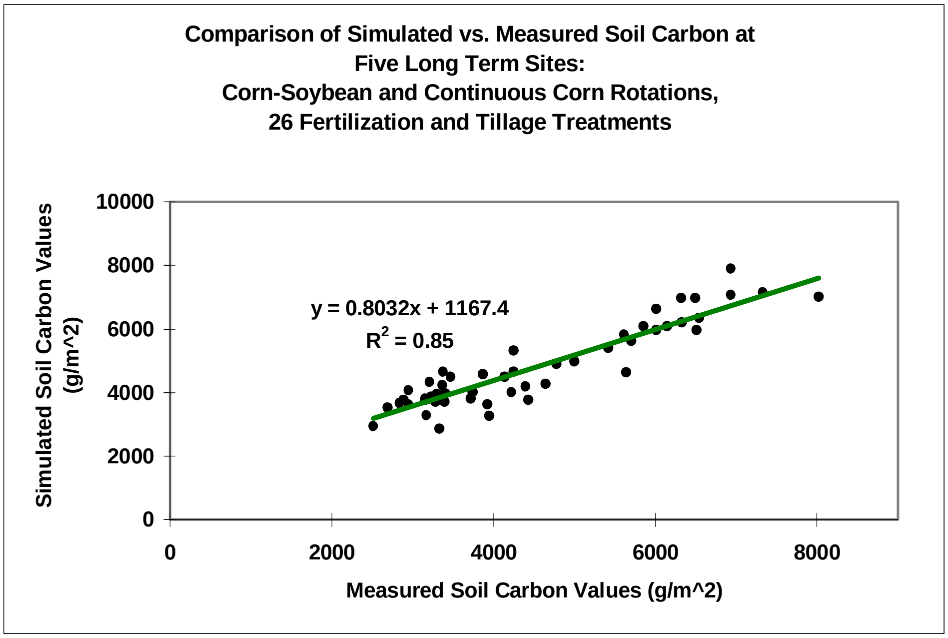


Figure 10: Simulated vs. measured soil C at 5 long term research sites

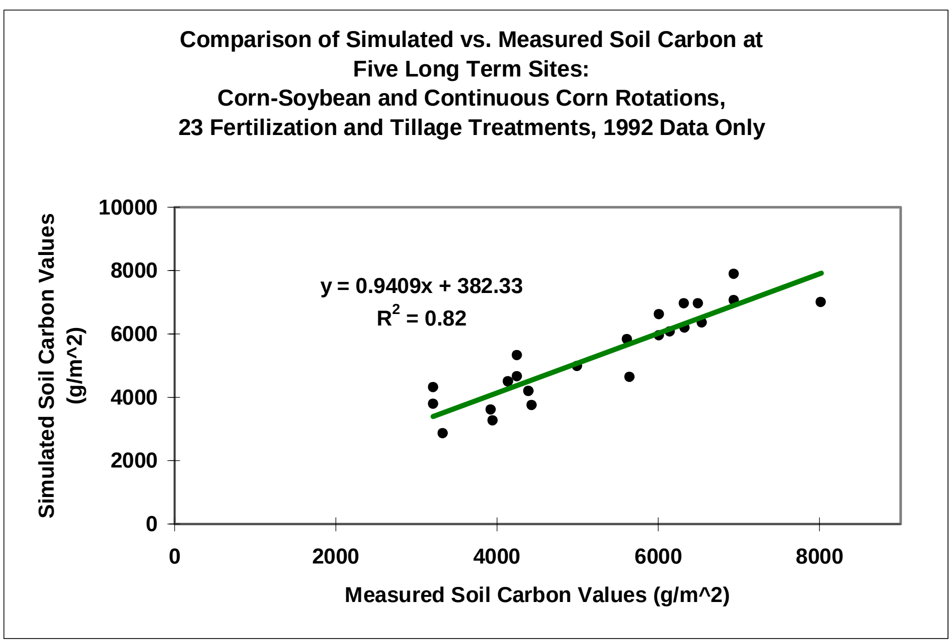


Figure 11: Simulated vs. measured soil C at 5 long term research sites (1992 data only)

Phase I: Methodology

Data on climate, soil, land-use and management practices were assembled from existing databases for each county as input to the Century model analysis. Monthly temperature (mean monthly maximum and minimum) and precipitation (monthly total) were developed for each county. We utilized the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) monthly climate variables described in the Phase II Century Modeling section in this report (Daly et al., 1994).

County-level soil attributes were derived from the State Soil Geographic Database (STATSGO) at the component level (i.e., soil series) within soil associations (USDA-SCS, 1994). For each county, area-weighted frequency distributions of soil types were determined based on the relative proportion of component soils within each soil association. Soil types for application in the model were grouped according to surface texture (0-20 cm) and classification as hydric or non-hydric (poorly drained or well-drained soils, respectively). All soils are considered that represent an area greater than 120 hectares (~300 acres) as described in the Phase II Century Modeling section in this report.

Land-use and management data were compiled from a variety of other sources including data on Conservation Reserve Program (CRP) contract acreage (USDA-FSA, 2000); National Agricultural Statistics Service (NASS) for state and county acres for crops grown by year, Figure 12, (NASS, 1999); area by tillage practice and crop compiled by the Conservation Technology Information Center (CTIC, 1998); and field operation scheduling and fertilizer use (provided by NRCS staff in Indiana). Data on manure applications were derived from a 1974 report (USDA Economics, Statistics, and Cooperatives Service, 1978) that reported rates, manure N content, and percent of economically recoverable manure by county. These were related to livestock numbers for 1974 in order to get estimates of the manure applications as a function of livestock numbers. We then used NASS reports of annual hog and cattle numbers, to estimate the amount of manure produced and applied to cropland for the other periods of the simulation. We assumed that manure was applied to second-year corn or to first-year corn in the case of corn-soybean rotations. To help regionalize the data, Indiana NRCS clustered the counties into nine management zones based on currently used areas for on-going conservation programs, Figure 13.

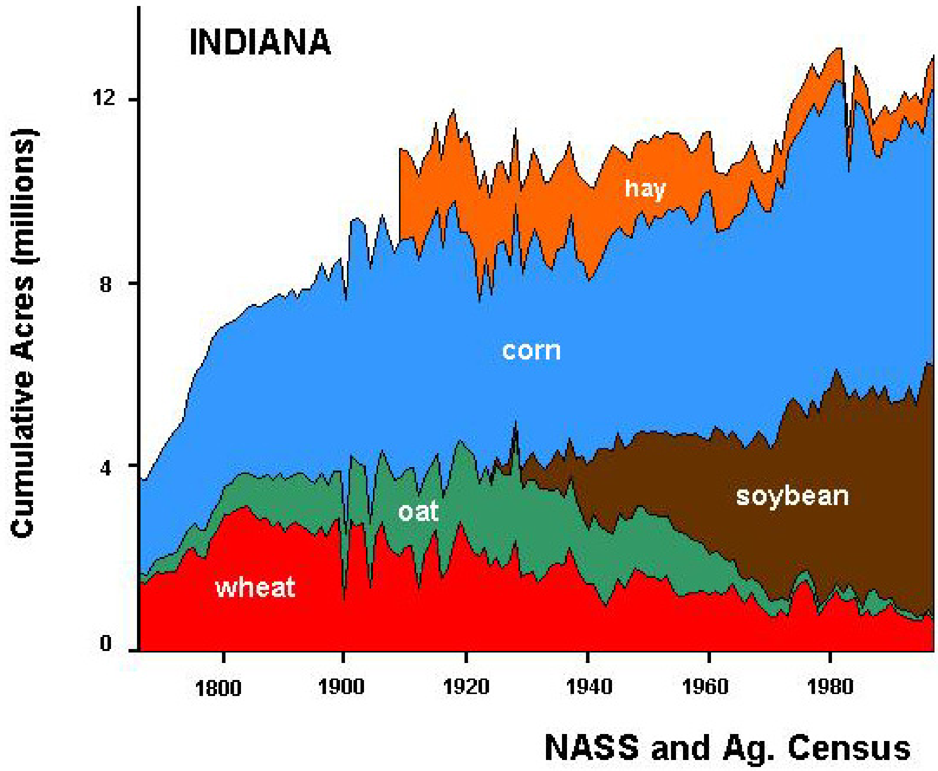


Figure 12: Crop changes from plow out to present

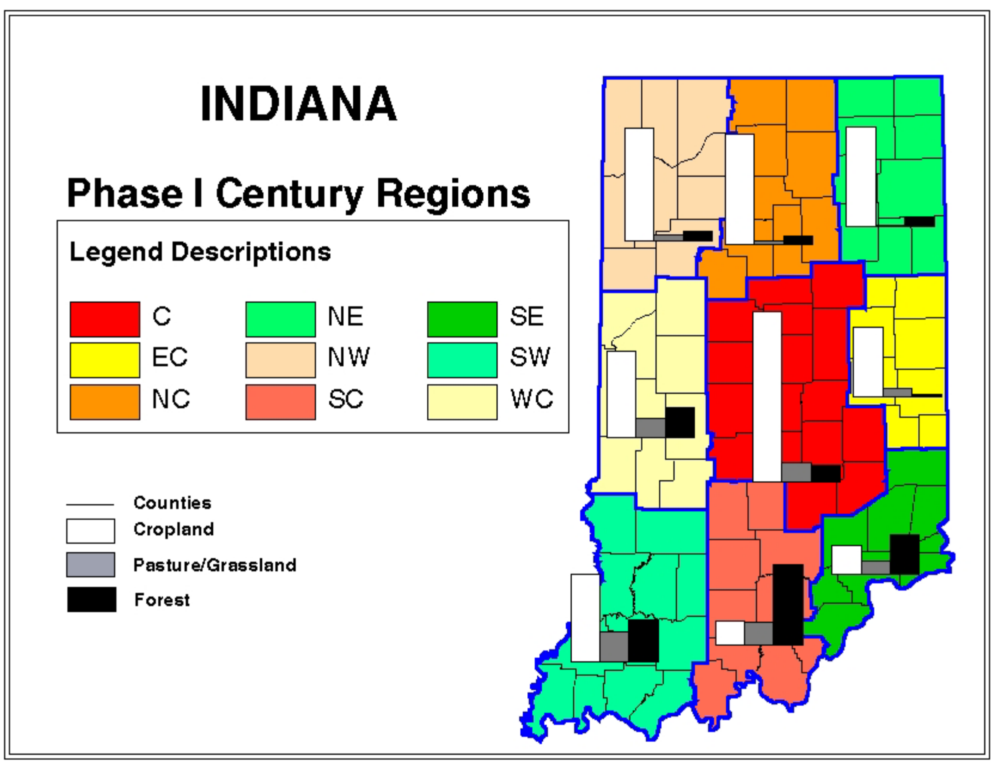


Figure 13: Phase I management zones

Cropping systems were then estimated for various time frames to best represent each management zone using the acreage of various crops reported by NASS and discussions with Indiana NRCS personnel (Table 1). From 1984 to the present, 4 crop rotations were applied to each management zone to reflect current practices. These included continuous corn, corn-soybean, corn-soybean-wheat and corn with 3 years of hay. We also simulated a grass planting to reflect lands that were enrolled into CRP. Tillage up to 1984 was assumed to be intensive as defined in the Phase II Century Modeling and Analysis section of this report. After 1984, intensive and no tillage systems were modeled. Assumptions for fertilizer use and harvest method were based on the sources cited above, and shown in Table 2. These management scenarios were then run for each county (within an NRCS management zone), and for each of the soil types within each county, as derived from the STATSGO analysis using the mean climate data for the county.

Table 1: Cropping systems by management zones.

Region	Time Period		
	1860-1930	1931-1960	1961-1984
NW	C-SG-H	C-C-S	C-C-S
NC	C-SG-H	C-SG-C-S	C-C-S
NE	C-SG-H	C-SG-C-S-H	C-S-W
WC	C-SG-C-H	C-SG-C-S	C-S
C	C-SG-C-H	C-SG-C-S	C-S
EC	C-SG-C-W-H	C-SG-C-S	C-S
SW	C-C-W-H	C-W-C-S	C-C-W-S
SC	C-C-W-H	C-C-SG-H	C-S-H
SE	C-W-H	C-SG-H	C-C-S-H

C= corn, O=oats, S=soybean, SG=small grain, W=wheat,H=hay (grass/legume mixture)

Table 2: Fertilizer use and harvest method for the State of Indiana.

Time period	N fertilizer	Harvest method
1860-1930	None	Grain + stover
1931-1960	20 kg ha^{-1} to corn 0 kg ha^{-1} to oats	Grain only
1961-1984	100 kg ha^{-1} to corn 20 kg ha^{-1} to oats	Grain only
1985-present	140 kg ha^{-1} to corn	Grain only

Phase I: Results

Conservation practices excluding the cultivation of organic soils were initially estimated as sequestrating 0.43 MMT of C in 1996 (Table 3). The cultivation of organic soils is estimated to be a source of 0.55 MMT of C in 1996 (Table 3). Estimates of areas for the conservation practices were provided from databases described above and NRCS personnel. Crops being grown using intensive tillage (includes all acres under reduced tillage systems) accounted for 81% of the area, but these lands were only providing 60,000 tonnes yr^{-1} of the C being sequestered. Cropland using no tillage accounted for 15% of the area and provided 300,000 tonnes of the C being sequestered. The amount of land that has been converted to CRP was 3% of the area and sequesters slightly more C than the area under intensive tillage. Soil C changes associated with cultivation of organic soils were not simulated by Century; instead, mean rates of C change (on a per hectare basis) for cultivation of organic soils were taken from Armentano and Verhoeven (1990). Organic soils that support crops account for 1% of the land evaluated, but these soils are responsible for 550,000 tonnes C yr^{-1} given back to the atmosphere. More research is needed on these soils to determine the affect of different management practices. Overall, this analysis demonstrates that cropland soils in Indiana are a slight source of C (120,000 tonnes C yr^{-1}) to the atmosphere.

The existing databases on land-use history, drainage, fertilizer amendments, crop rotations and tillage systems provided a good basis for the Phase I study, but they were limited in their ability to characterize local conditions. Thus a Phase II study was designed to help in bringing C sequestration information to the local land manager. The Phase II study utilized the information gained from the Phase I study, and expanded the scope and complexity of the analysis to include the local land managers' decision-making and expert knowledge to assist in providing inputs into the Century model. This additional information was gathered for each county in the state, using a new survey instrument -- the Carbon Sequestration Rural Appraisal (CSRA) -- (Brenner et al. 2002).

Table 3: Phase I: Summary of C sequestration rates

Management System	Metric Units			English Units		
	Hectare	Tonne C	Tonne CO_2	Acres	Ton C	Ton CO_2
Intensive Tillage	4,411,000	60,000	220,200	10,899,775	66,139	242,730
No Tillage	793,000	300,000	1,101,000	1,959,538	330,693	1,213,643
CRP Land	167,000	70,000	256,900	412,664	77,162	283,185
Cult Organic Soils	70,000	-550,000	-2,018,500	172,973	-606,271	-2,225,015
State Total	5,441,000	-120,000	-440,400	13,444,950	-132,277	-485,457

Phase II: Methodology

Initial Contacts And Expectations

On January 2000, state partners met with project staff from Colorado State University, Natural Resources Ecology Lab in Indianapolis, Indiana for the first time to discuss the project. The state partners are: USDA-Natural Resources Conservation Service (NRCS) state office; The Indiana Association of Soil and Water Conservation Districts, the Indiana State Soil Conservation Board, Division of Soil Conservation of the Indiana Department of Natural Resources and the Purdue Cooperative Extension Service. A representative of the National Association of Conservation Districts (NACD) met with the state partners on March 16, 2000 to discuss procedures for data collection, submission by districts of an invoice for payment and a state information and education plan. All 92 counties were involved in the project, and the 92 conservation districts provided local data through the use of the Carbon Sequestration Rural Appraisal (CSRA). NACD coordinated with the conservation districts and the state partners to assist in data collection and to establish an information and education program.

A training session was held on March 16, 2000 for NRCS and conservation district officials and statewide staff for technical support of the project, including instructions on completing the CSRA. Representatives of state partners and NACD presented the session by statewide closed circuit telecast provided by Purdue University.

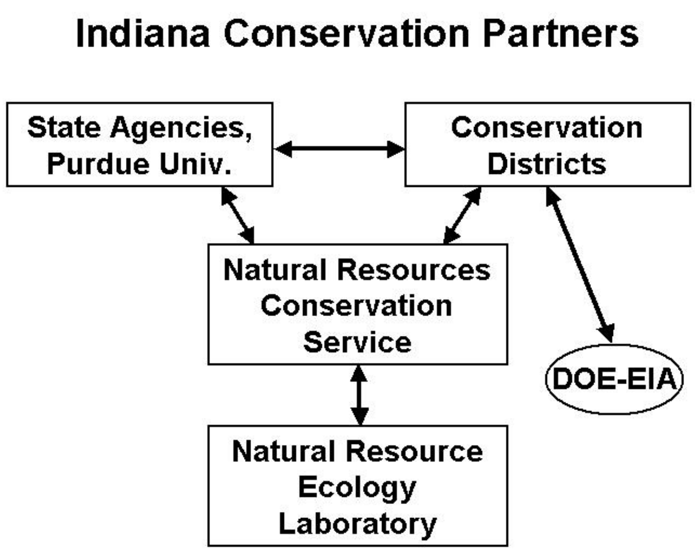


Figure 14: Indiana conservation partners

The conservation districts and local NRCS offices completed the CSRA during the spring of 2000, with 100% of the counties participating and electronically returning completed appraisals to NREL for use in the model simulations. Figure 14 is a flow diagram of the conservation partners involved in Phase II of this project and details how the involved parties communicated and the process of how data is transferred between groups. Figure 15 summarizes the CSRA process.

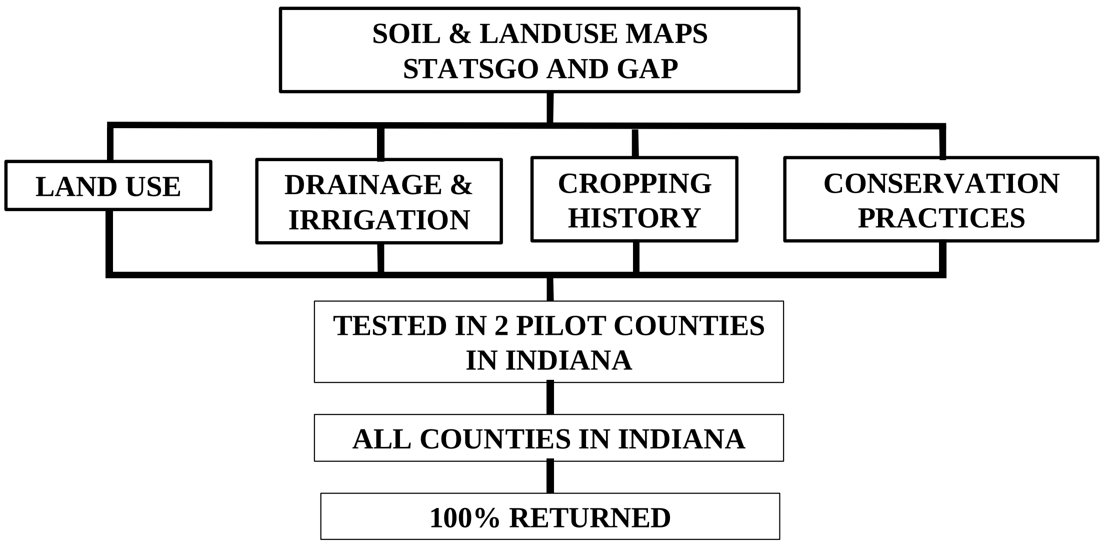
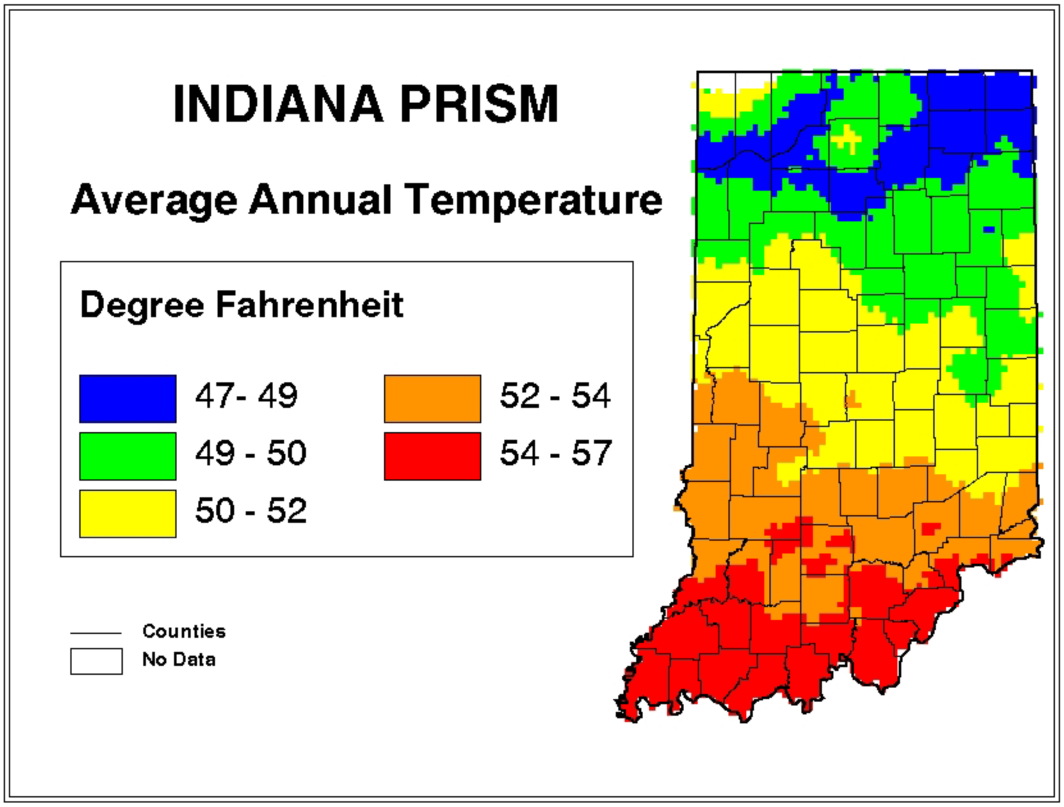


Figure 15: CSRA process

Databases

Data on climate, soils, land use, and management practices used in the analysis were assembled from a variety of sources. Individual counties are the spatial unit for representing climate factors. In other words, counties were assumed to be homogeneous with respect to the temperature and precipitation driving variables.

Temperature (mean monthly maximum and minimum) and precipitation (monthly total) were obtained from the PRISM monthly climate data set (Daly et al., 1994). PRISM uses point data from the U.S. network of weather stations and a digital elevation model (DEM) to orographically adjust climate variables for 4 km grid cells across the coterminous U.S. The data used in our analysis consisted of long-term (1961-1990) monthly averages (Figure 16). Area-weighted mean values of monthly temperature and precipitation variables were calculated for each county.



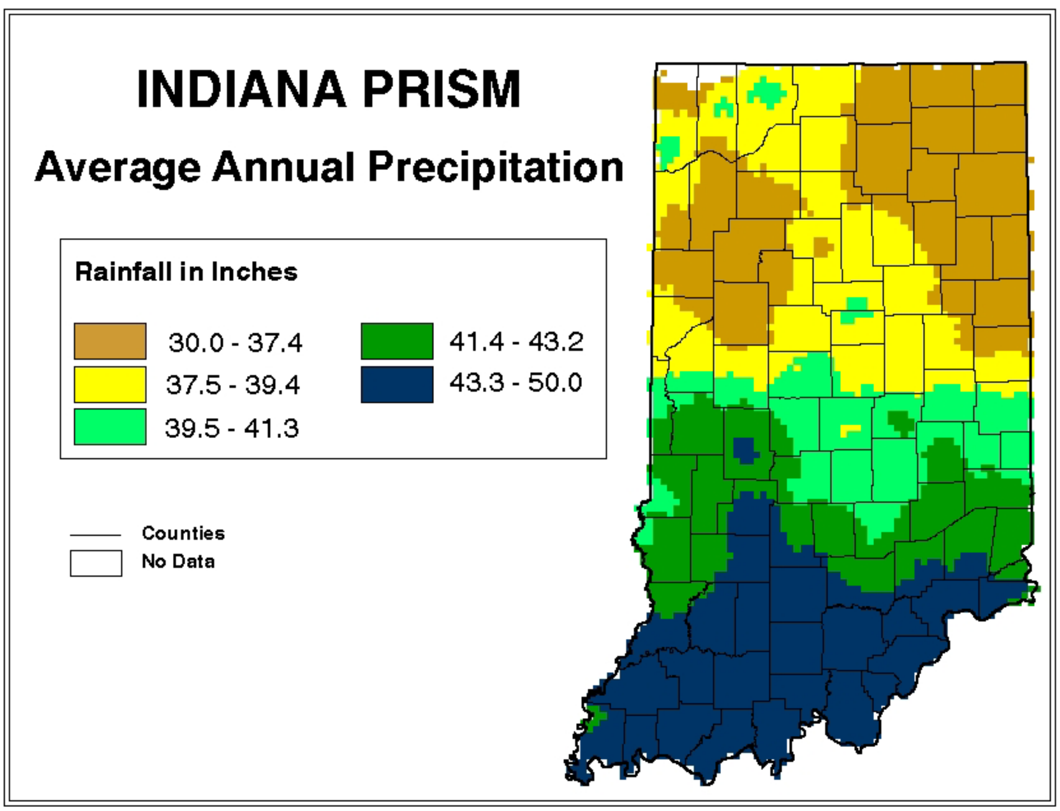


Figure 16: PRISM climate variables

County-level soil attributes were derived from analysis at the component level (i.e., soil series) within soil associations of STATSGO (USDA-SCS, 1994). For each county, area-weighted frequency distributions of soil types were determined based on the relative proportion of component soils within each soil association. Soil types for application in the model were grouped according to 0-20 cm surface texture (Figure 17) and classification as hydric or non-hydric (Figure 18).

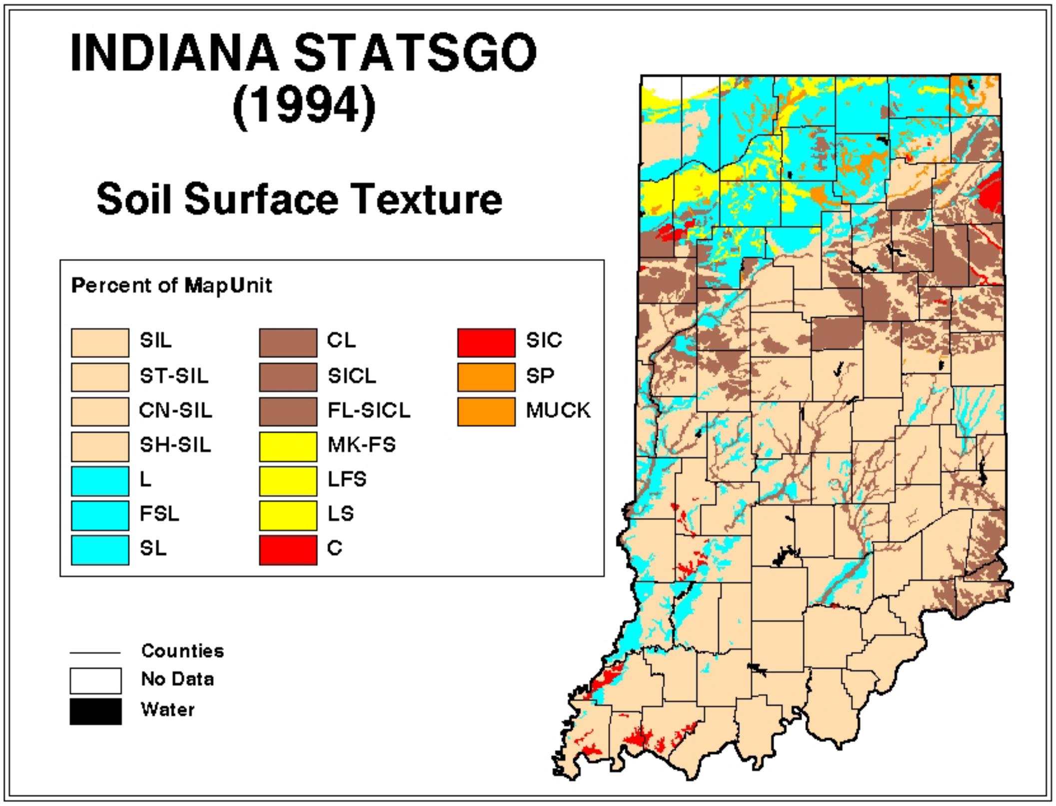


Figure 17: STATSGO soil surface textures

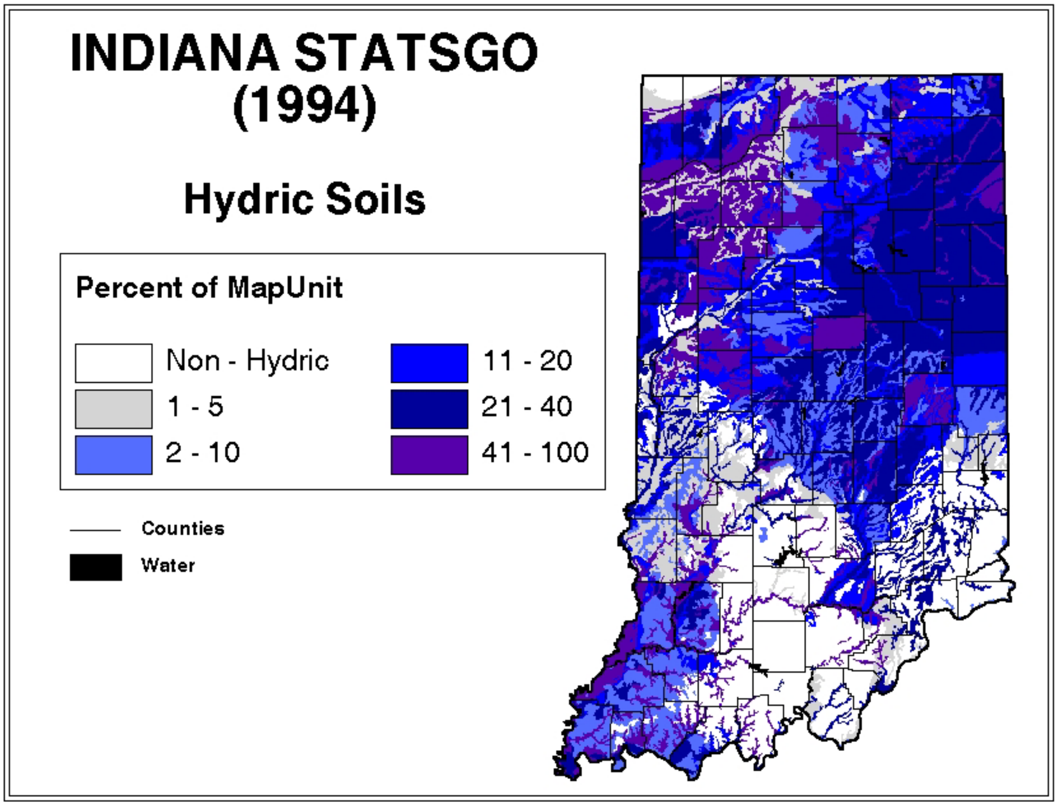


Figure 18: Percent of hydric soils from STATSGO

Current land use/land cover was obtained from the Geographic Analysis Program for Biodiversity, 1991-1992 (GAP) records (Scott et al., 1997) and provides the management system by major types including cropland, grassland, forest land, bottom land, urban land and water (Figure 19). An enclosed CD ROM contains the maps developed for each county as post-script files. STATSGO soil maps and current land cover maps (GAP) were integrated together and developed for each county (Figure 20).

Within each county, all soil types with an area greater than 120 hectares (~300 acres) are included in the analysis, except for areas where crops cannot be grown, such as rocky outcrops and water. Figure 21 and 22 are examples of the soil types that were included in the analysis for Crawford and Tippecanoe Counties and illustrate the variability in soil types throughout the state. Depending on the individual county, the major soil types yielded two to sixteen distinct soil types per county.

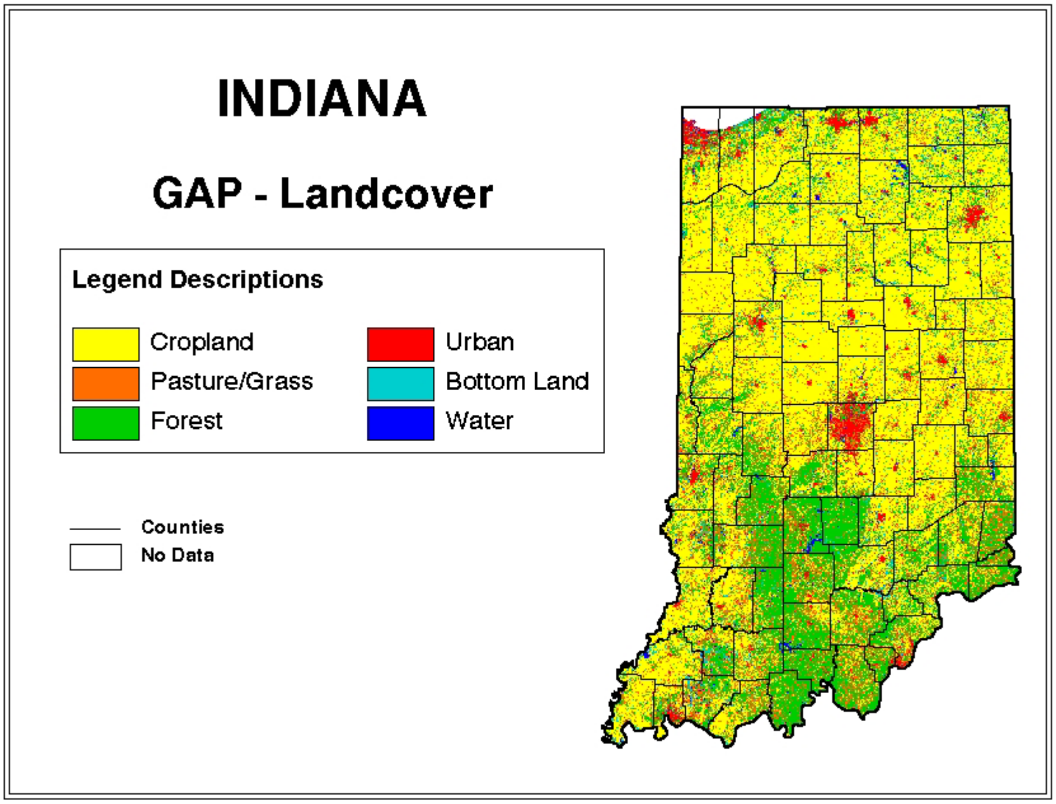


Figure 19: GAP landcover by management type

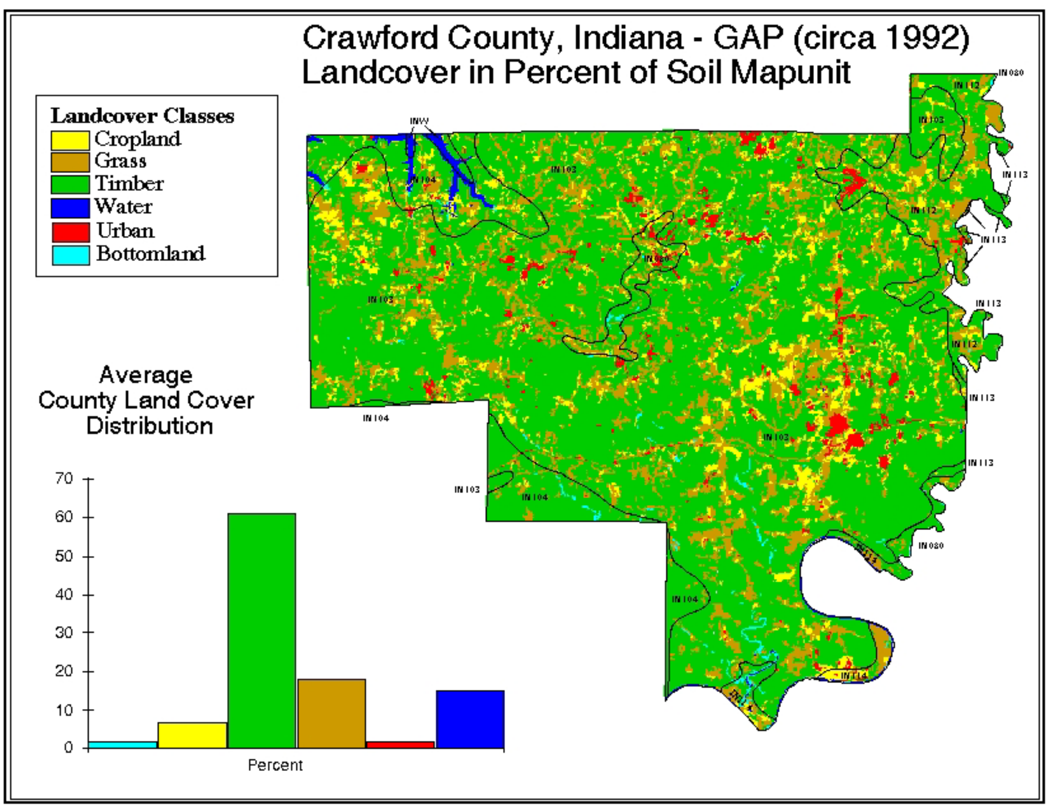


Figure 20: Crawford county STATSGO soil and GAP landcover

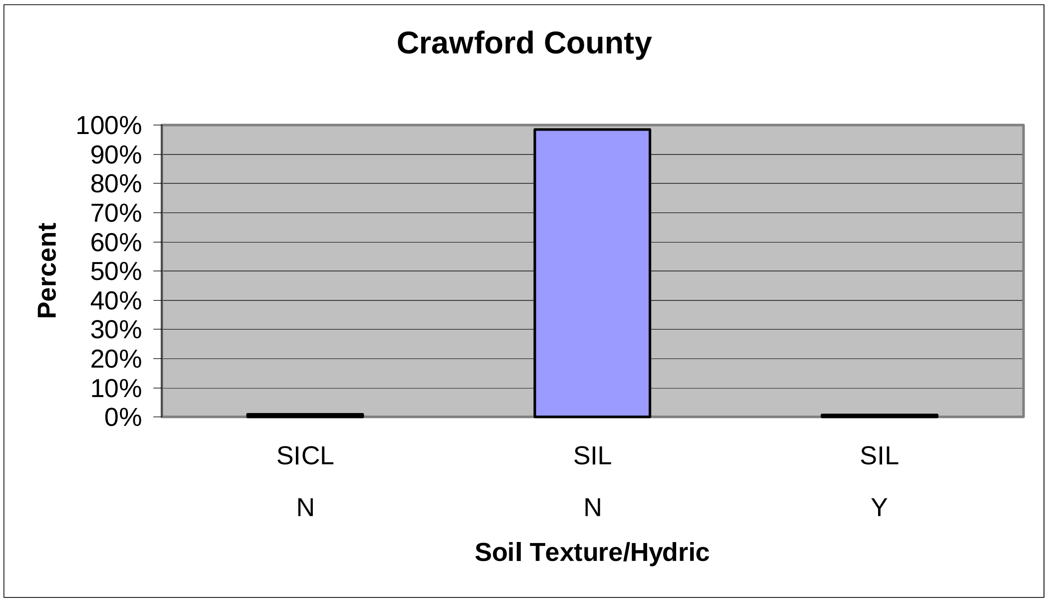


Figure 21: Crawford county modeled soil types

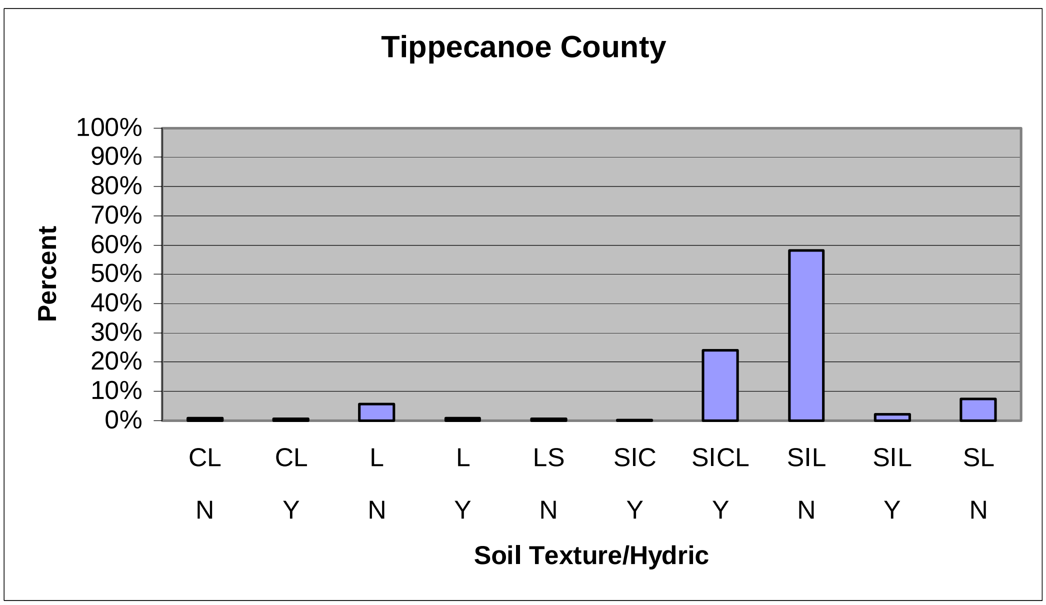


Figure 22: Tippecanoe county modeled soil types

CSRA Data Collection

The CSRA consists of a series of data sheets detailing historical land-use, dominant management practices (drainage, irrigation, crop rotations, tillage and fertilization) over time, and installation of conservation practices (e.g., CRP, grassed waterways, buffers) compiled by local experts in each county. This procedure was successfully used in Iowa to gather data from conservation districts (Brenner et al., 2001). A two-county pilot study was conducted to validate the availability of local data and the willingness of conservation districts to provide data and to further refine the process of collecting local data at a very large scale for all 92 counties. Allen and Gibson Counties participated in the 1999 pilot study. Their respective locations in Indiana provide a good mix of North-to-South and East-to-West landscape positions. Information and ideas provided by the conservation districts and NRCS people in the pilot counties were used to finalize the CSRA format. CSRA as used in Indiana was an Excel spreadsheet containing a series of work sheets. Excel spreadsheets were electronically transmitted from Fort Collins to Indiana, completed at the local level and electronically transmitted back to Fort Collins. Table 4 details the types of data provided by the Conservation Districts through the use of the CSRA.

Table 4: Types of data provided by the CSRA

Title	Description
Current Land Use Information	Land use by soil map unit
Drainage Information	Installation of drainage by soil map unit
Irrigation Information	Installation of irrigation by soil map unit
County level farming histories	Cropping, fertilizer and tillage practices
Annual conservation practices	Conservation practices installed

Quality control of the CSRA data was necessary to provide consistent terminology, definitions, and units between counties. The data input on CSRA forms is not directly available from any other source. Other sources include some similar data. Quality control was also necessary to ensure similarity between CSRA and other published data where appropriate. Developing tools to analyze and compare these data took a substantial amount of effort.

The CSRA spreadsheets (Appendix A) are supported by background information from published databases. Current land use/land cover obtained from the 1991-1992 GAP records and was used along with land use and management data compiled from a variety of other sources. These other sources include USDA Conservation Reserve Program (CRP) contract acreage obtained from USDA Farm Services Agency (FSA); National Agricultural Statistics Service (NASS) county level acres harvested and yield data obtained from <http://www.usda.gov/nass/>; Transect, version 2.12, county level data with acres of crops grown under different tillage regimes per year obtained from Purdue Research Foundation; and annual residue management data obtained from the Conservation Technology Information Center (CTIC) through their electronic data access and retrieval system called WinCEDAR.

Two Excel spreadsheets with multiple worksheets were developed to automatically consolidate data from submitted CSRA sheets, CTIC data, Transect data, NASS data and CRP data. All data was consolidated at the county level. Most of the data was also consolidated at a yearly level during the late 1980's and through the 1990's.

Conservation Reserve Program (CRP) data from USDA FSA was summarized into total acres of new grass plantings in CRP signups 1-18, total acres of CRP grass contracts, total acres of new tree plantings in CRP signups 1-18, total acres of CRP tree contracts and total acres of CRP wetland contracts for each county. Acres of active CRP grass and active CRP tree contracts as of September 15, 2000 were summarized and compared by county. These acres were compared to total acres of grass, tree and wetland acres from the CSRA sheets. Because the total acres of grass, tree and wetland acres reported on CSRA sheets should all CRP lands in addition to other land use changes such as addition of grassed waterways, buffers, windbreaks and other conservation practices. We expected the CSRA values to be at least as high as the CRP values. We discussed inconsistencies with Indiana, and modified some CSRA sheets as needed.

This spreadsheet summarized acres of total cropland that is planted in corn, soybeans and wheat according to CSRA forms. These acres were compared to acres of cropland harvested in corn, soybeans, oat, wheat and hay from NASS. We expected these areas to be relatively close together. When significant differences were noted, the data was discussed with Indiana. A few crop rotations were adjusted in some CSRA forms to better match NASS data. As an example, many of the CSRA forms indicated that corn-soybean is the primary current rotation. However, some counties grow considerably more corn than soybeans because some lands are generally in continuous corn, while others raise considerably more soybeans because corn-soybean-soybean rotations are popular in some counties.

This spreadsheet also summarized and compared drainage data. Data was summarized for each STATSGO Map Unit IDentifier (MUID) in each county. Analysis included total acres in the MUID, acres of cropland in the MUID, and percent of MUID drained in both early and late drainage periods. We compared total acres drained in each time period by MUID to acres of hydric soil to acres of cropland. Because we don't expect that much non-cropland to be drained, we expected total acres of cropland to be equal or greater to total acres drained. We also expected that total acres drained would not be significantly greater than hydric acres in most cases. We also expected the first drainage time period would be centered in the very early 20th century, and the second time period would be centered somewhat after WWII. When significant differences were noted, the data were discussed with Indiana and adjustments to the CSRA were made.

County level corn and wheat crop yields from CSRA were plotted against total pounds of N fertilizer applied per acre for the 1921-1950, 1951-1970, 1971-1990 and 1991-present time periods. Line of best fit for each time period was also plotted. See Figure 23 for corn. Outlier points were reviewed and either crop yield or amounts of fertilizer applied were considered for adjustment. Potential crop yield adjustments were compared to NASS yield data. Total CSRA reported N fertilizer applied were added for the entire state and compared to USDA Economic Research Service fertilization data published at < http://usda.mannlib.cornell.edu/>.

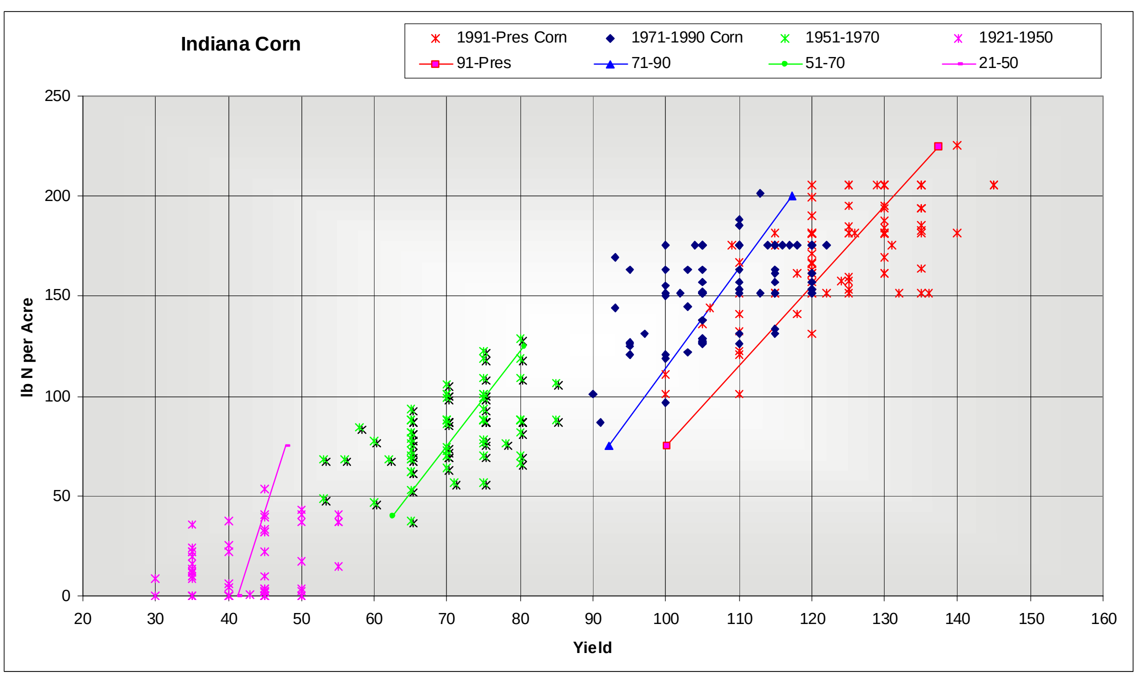


Figure 23: County level corn yields vs. N fertilizer applied from CSRA

Acres harvested and yield of corn, soybeans and small grain, from NASS, were summarized by county by year by tillage system. Acres of crops grown under various tillage systems from CTIC were summarized by county by year. Acres of crops grown under different tillage systems from Transect were summarized by county by year. CSRA data was included. These four databases were combined into one spreadsheet such that several graphs could be easily displayed. Selecting any Indiana county from a pull down menu would display four separate graphs.

The most valuable graph displayed total acres of cropland from NASS, acres of No-Till from CTIC, acres of cropland with >15% residue from CTIC, total acres of cropland from Transect, acres of cropland with >16% residue from Transect, total acres of No-Till cropland from CSRA and total acres of Rotational No-Till cropland from CSRA. This data was graphed over time from 1985 through 2000 (Figure 24).

Estimates of the percent of total cropland in each of the five crop rotations were provided as part of the information collected in the CSRA. Indiana Transect and CTIC reports the area in various tillage systems by individual crops on an annual basis; however, it does not differentiate between long-term no tillage practices versus intermittent or 'rotational no tillage' (i.e., tilled corn – no-tilled soybean rotations). For agronomic reasons, (i.e., low residue amounts under soybean and use of herbicide-resistant soybeans), the percent area of soybeans managed under no-till was generally higher than for corn. Thus, to estimate the area of continuous no tillage as opposed to rotational no tillage, we reviewed the percent area of continuous no tillage on the acreage of corn under no tillage, assuming that if corn were no-tilled it was likely that other crops in the rotation (e.g., soybean or wheat) would also be no-tilled. The remaining area reported as no tillage by Transect or CTIC was assumed to represent rotational no tillage and was included as part of the moderate tillage category. The moderate tillage category also included areas reported as mulch-till and ridge-till by Transect or CTIC. The area under intensive tillage was then calculated by difference.

Areas under the different tillage systems were estimated from the CTIC database, which has reported area by tillage system and county on an annual basis since 1989 and the Transect database, which has reported area by county and tillage system on a spotty basis since 1989.

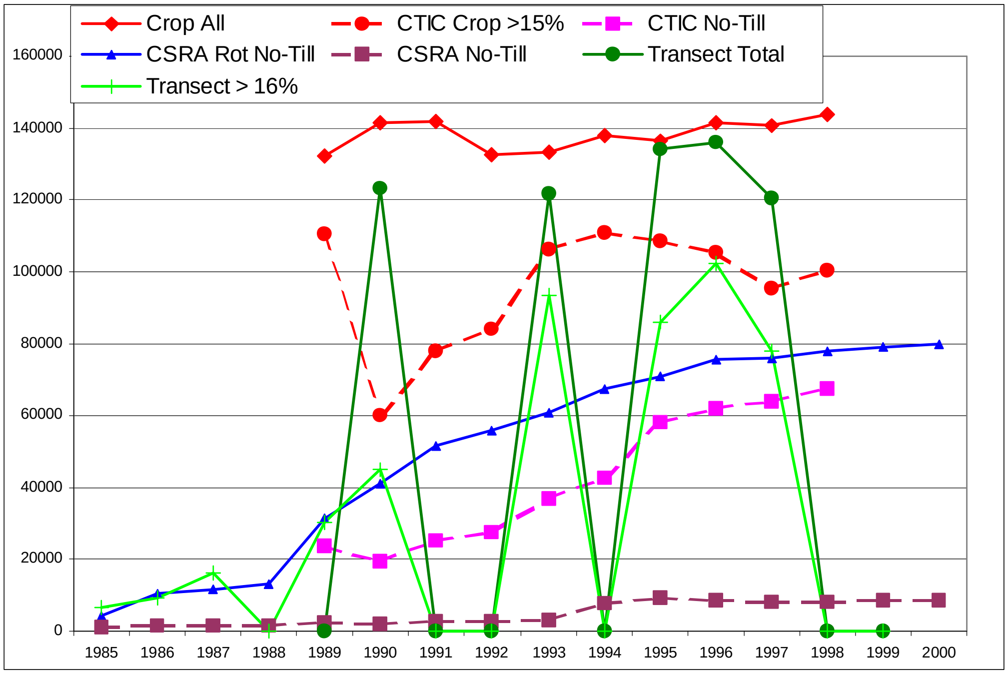


Figure 24: Bartholomew County tillage data (Transect data was not availabefor 1988, 1991, 1992, 1994, 1998 and 1999)

A second important graph displayed total acres (All) of corn, soybeans and small grains and acres of corn, soybeans and small grains with less than 15% residue (ZF) from CTIC data (Figure 25).

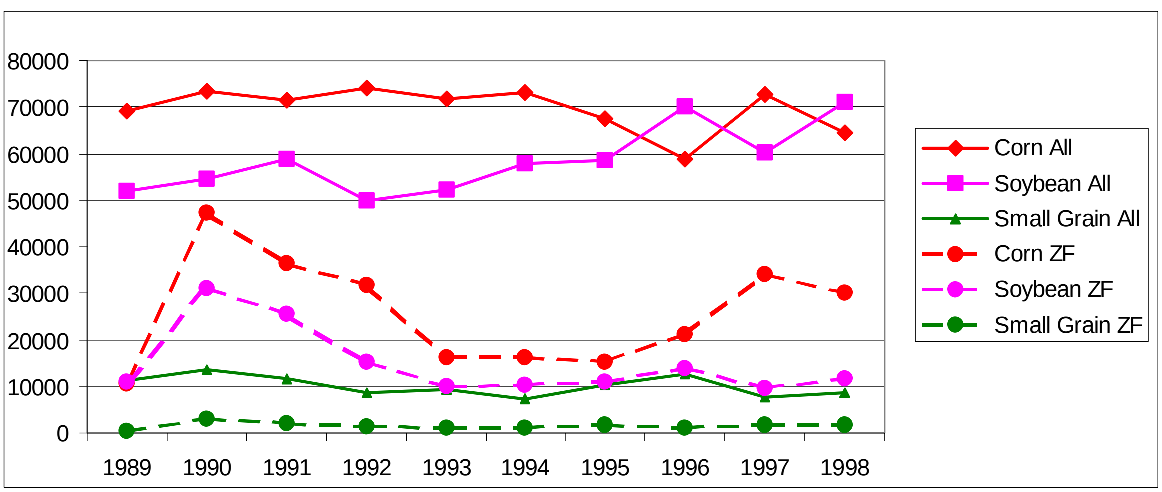


Figure 25: Bartholomew County comparison of total crop acres (All) and CTIC crop acres with less than 15% residue

A third graph displayed acres of Highly Erodeable Land (HEL) acres and HEL acres treated from CTIC and acres of CRP acres by year from CSRA (Figure 26). The fourth graph displayed total acres of corn, soybeans, small grain, forage and pasture from CTIC.

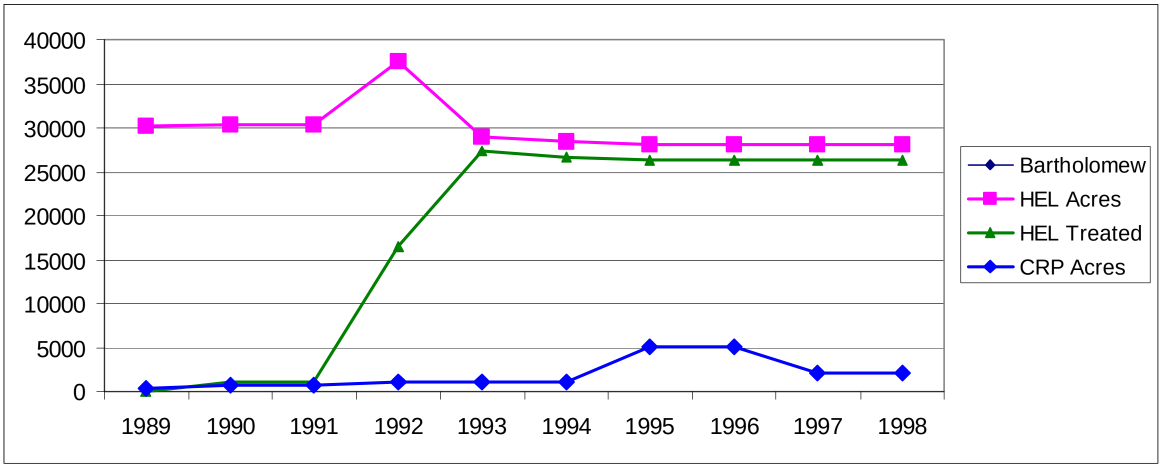


Figure 26: Bartholomew County total acres of HEL, HEL land treated and CRP from CTIC

Definitions used by CTIC, Transect and CSRA are somewhat different for what lands are considered No-Till or Rotational No-Till. Due to these different definitions, different interpretations by various data collectors and other factors, we did not expect the graphs would look identical, but we did expect some similarities and trends.

We expected the CTIC total crop acres to be roughly equal to Transect total crop acres. We expected CTIC > 15% residue acres to be roughly equal to Transect > 16 % residue acres. We expected the sum of CSRA No-Till and CSRA Rotational No-Till to be equal or lower than Transect > 16 %. We expected CSRA CRP acres to be equal or lower than HEL treated acres from CTIC. Due to real differences in definitions, differences in data collection none of these expectations or rules were considered hard and fast. When these expectations were not met, we discussed the data with Indiana. In some instances, we modified CSRA data to more closely approximate data from other sources. In other instances, we believed the CSRA data to be appropriate, even though it didn't always approximate data from these other sources.

CSRA Relational Database

A relational database was developed to manage the data provided by the various Indiana counties for the county level assessments. This database was necessary to define the relationships between the various crops, tillage operations, rotations, and cropping histories. The data were then fed directly from the database to a series of PERL computer scripts that built the schedule files necessary to run the Century model for the various combinations of crop histories, soils types, and hydric conditions. Developing the database and moving the data between the data entry spreadsheets to the database took a substantial amount of effort. Quality control of the CSRA data was necessary to provide consistent terminology, definitions, and units between counties. The various tillage events then had to be organized into tillage sequences that the Century model could interpret appropriately. Finally, the data had to be organized from the spreadsheets into a set of standard query language (SQL) strings in order to insert the data into the relational database. The result was a straightforward and highly adaptable relational database structure that improved the efficiency of the model runs. The final data set was the end result of dozens of sets of modeling runs. Each of the interim model runs that was done prior to the final result led to new discoveries about the data set, requiring minor modifications and corrections to the input data. Having the input data in a relational database substantially eased the process of doing the model reruns.

Century Modeling and Analysis

Initial model parameters were set according to the procedure outlined in the Century Model Description section of this report. The equilibrium Century runs provide the initial soil organic matter levels in the different pools. The model then simulated changes in soil C as a function of past agricultural practices based on dominant crop rotations and management practices reported in the CSRA. The average date reported for the onset of cultivation occurred during the 1840's-1850's for most counties, and cropping histories were divided into periods between 1840-1860, 1861-1920, 1921-1950, 1951-1970, 1971-1990 and 1991-present. Crop production potentials were also varied over time to mimic long-term changes in crop yields as reported by NASS, with yields increasing by 1-2% per year since the 1950s. For each time period, the local experts completing the CSRA specified the crop rotations and management practices (i.e., tillage, fertilization, manuring) that were representative for their area. Each county reported one to six representative histories prior to 1974 and the average was nearly three histories per county. Most counties reported similar trends in the dominant cropping practices with corn, oats, wheat, and hay as the dominant crops prior to 1950, followed by a rapid shift towards feed-grain dominated rotations (i.e., corn and soybean) and a substantial reduction of hay in rotation.

Drainage dates were provided by the CSRA for each county. The hydric soils were drained in two phases as reported in the CSRA with the first phase being a partial drainage usually in the early 20th century, and more complete drainage by 1940-1970. Appendix B details the drainage dates for each county. Using the relational database, the CSRA provided the crop rotation, tillage practices and fertilizer used in the individual counties. Each individual county has its own history beginning at the time the soils were broken out for cultivation and extending until 1974. Starting in 1974, five crop rotations (continuous corn, corn-soybean, corn-soybean-wheat-alfalfa-alfalfa, corn-soybean-soybean, and corn-soybean-wheat), for each of three tillage regimes (intensive tillage, moderate tillage and no tillage), were simulated for a 20-year period (1974-1994) in each county. Intensive tillage was defined as multiple tillage operations every year, including significant soil inversion (i.e., plowing, deep disking) and low surface residue coverage. This definition corresponds to the intensive tillage and ‘reduced’ tillage systems as defined by Conservation Technology Information Center (CTIC, 1998). No tillage was defined as not disturbing the soil except through the use of fertilizer and seed drills and where no-till is applied to all crops in the rotation. Moderate tillage made up the remainder of the cultivated area, including mulch tillage and ridge tillage as defined by CTIC (CTIC, 1998) and intermittent no-till (see below).

To simulate changes due to the Conservation Reserve Program (CRP), all five crop rotations, under intensive tillage, were modeled with a change to CRP grass plantings for a ten-year period, starting in 1985. Two different CRP grass plantings were modeled for each of the five crop rotations. One CRP planting contained 25% legume and 75% grass in the mixture. The other planting contains 100% grass planting. Table 5 shows the combinations of crop rotations, CRP, and tillage regimes modeled from 1974 to 1994.

Table 5: Crop rotations and tillage interactions: 1974-1994

Experiment	Description
1	Continuous Corn, Intensive Tillage
2	Continuous Corn, Moderate Tillage
3	Continuous Corn, No Tillage
4	Continuous Corn to CRP (25% legume, 75% grass) in 1985, No Tillage
5	Continuous Corn to CRP (100% grass), No Tillage
6	Corn-Bean, Intensive Tillage
7	Corn-Bean, Moderate Tillage
8	Corn-Bean, No Tillage
9	Corn-Bean to CRP (25% legume, 75% grass), No Tillage
10	Corn-Bean to CRP (100% grass), No Tillage
11	Corn-Bean-Wheat-Alfalfa-Alfalfa, Intensive Tillage
12	Corn-Bean-Wheat-Alfalfa-Alfalfa, Moderate Tillage
13	Corn-Bean-Wheat-Alfalfa-Alfalfa, No Tillage
14	Corn-Bean-Wheat-Alfalfa-Alfalfa to CRP (25% legume, 75% grass), No Tillage
15	Corn-Bean-Wheat-Alfalfa-Alfalfa to CRP (100% grass), No Tillage
16	Corn-Bean-Bean, Intensive Tillage
17	Corn-Bean-Bean, Moderate Tillage
18	Corn-Bean-Bean, No Tillage
19	Corn-Bean-Bean to CRP (25% legume, 75% grass), No Tillage
20	Corn-Bean-Bean to CRP (100% grass), No Tillage
21	Corn-Bean-Wheat, Intensive Tillage
22	Corn-Bean-Wheat, Moderate Tillage
23	Corn-Bean-Wheat, No Tillage
24	Corn-Bean-Wheat to CRP (25% legume, 75% grass), No Tillage
25	Corn-Bean-Wheat to CRP (100% grass), No Tillage

From 1994, all of these options were continued for an additional 20 years, along with all combinations of changes between crop rotations, CRP, and tillage regimes. This provided simulations for each soil texture/hydric combination in each county and over 800,000 simulations for the entire state. The CarbOn Management Evaluation Tool (COMET) database provides the rate of soil C change for each of these management combinations and conservation practices.

Detailed analysis of these rates showed that Century initially overestimated corn grain yields when compared to NASS county averages and C inputs by up to 60 % for most of the southern counties. Further analysis of these southern counties reveled that soil depth was limited and many counties have soil slopes exceeding 8% (Figures 27 and 28). We also looked at the 97 NRI cropland sites for each county and plotted the weighted mean slope against the NASS corn yields for the 1990's (Figures 29). This shows that these southern counties (circled) are less productive and we attribute this to soil factors. We reduced the soil depths in 21 southern counties to help address these issues and rerun all the simulations. These new runs show that Century is estimated 0-30% higher corn grain yields than current NASS averages across the state. We feel that the Century yield estimates reflect additional C inputs into the system which are not reflected in harvested datasets, such as harvest losses (Hanna and Van Fossen, 1990; NDSU, 1997), insect damage and severe weather events (i.e. hail, flooding, ect).

Additional information was compiled from the literature to estimate net soil carbon changes for minor land use practices that were not modeled by Century, including changes associated with tree conversion and wetland restoration on former cropped land and cultivation of organic soils. Mean rates of carbon change (on a per hectare basis) for cropland conversion to trees were taken from Lal et al. (1998). The rates for cropland conversions to wetland and cultivation of organic soils were taken from Armentano and Verhoeven (1990). CSRA provides the area associated with the tree conversion and wetland reversion conversion practices.

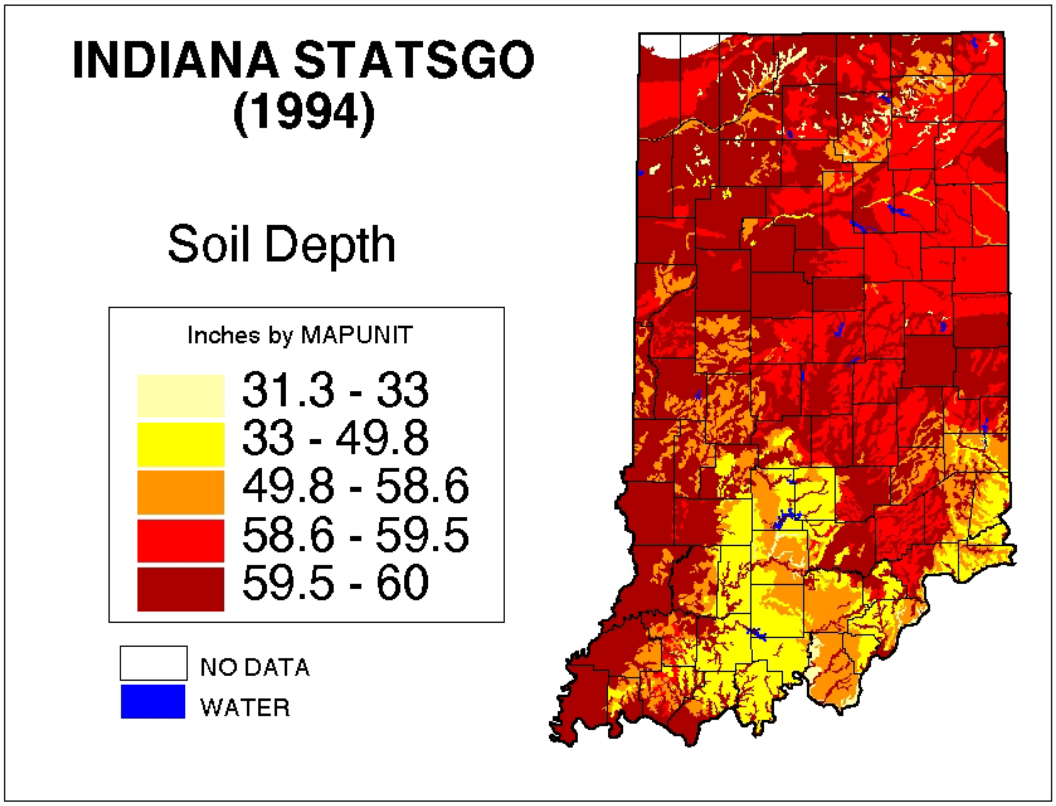


Figure 27: STATSGO soil depth

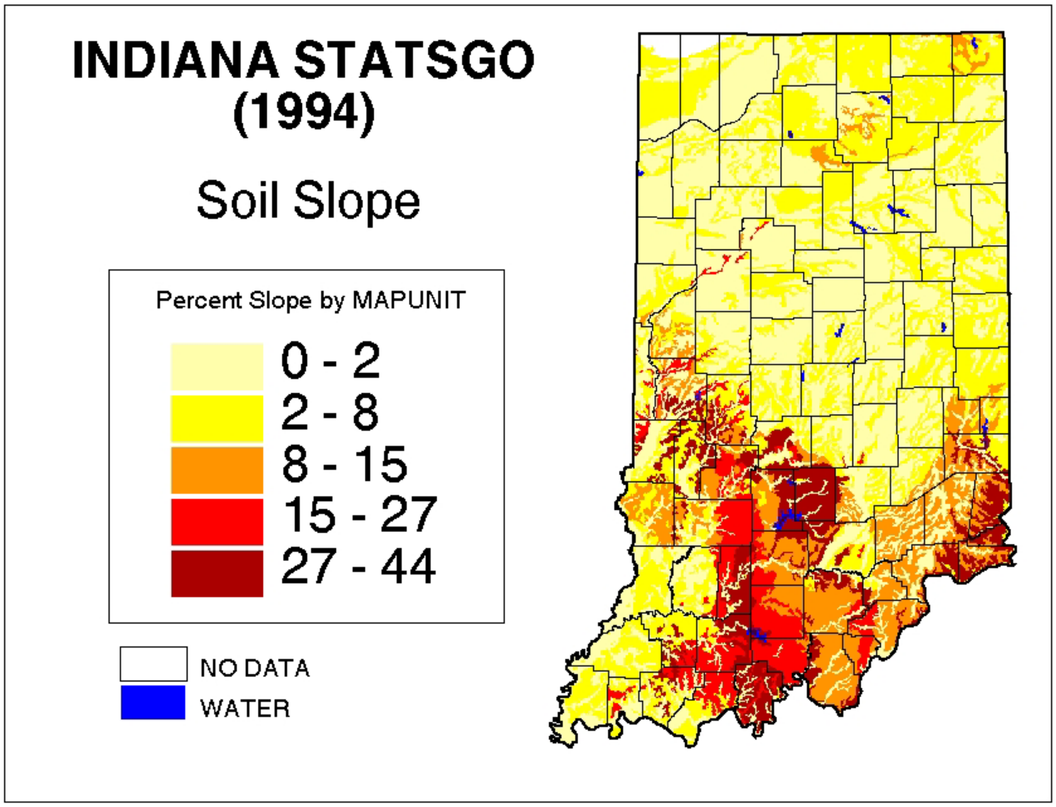


Figure 28: STATSGO soil slope

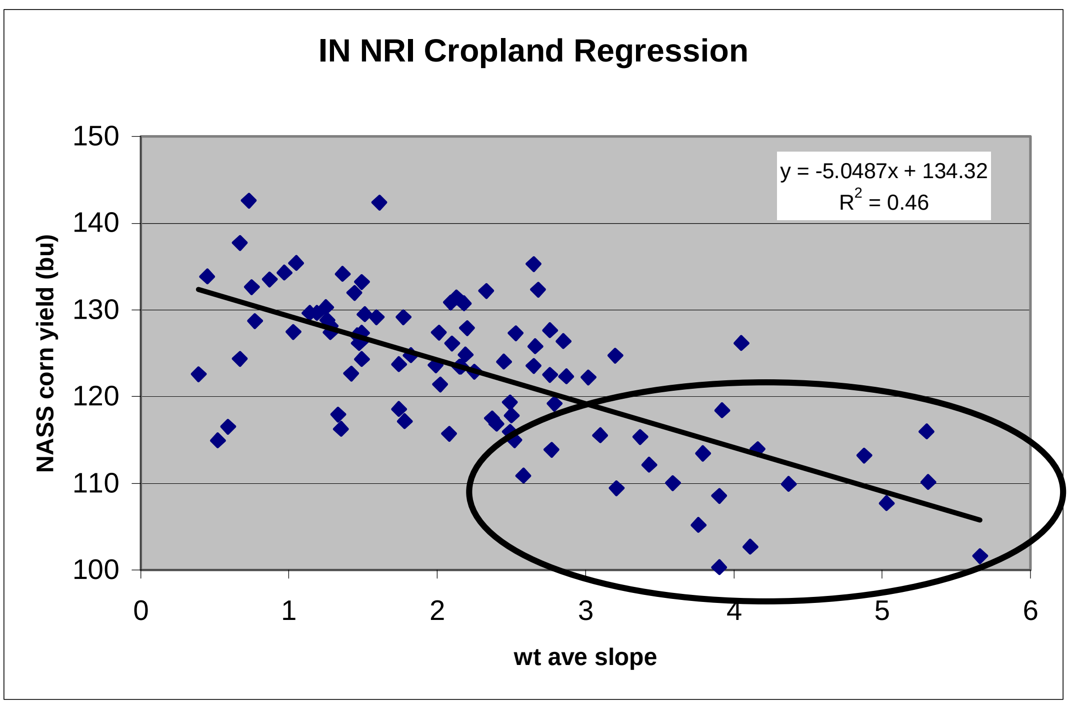


Figure 29: NRI cropland county weighted average soil slopes vs. NASS corn yields

Phase II: Results

State Summaries

The principle management trends affecting simulated soil C stock changes for the state of Indiana were the increase in the adoption of moderate tillage and no tillage systems for row crop production and the introduction of the CRP. In addition, there is a general long-term trend of increasing crop residue inputs, associated with productivity gains (on the order of 1-1.5% per year) since the 1950s (Reilly and Fuglie, 1998), which contributes to increasing soil C stocks in the annual crop systems, even for some intensively tilled soils.

No tillage and moderate tillage systems have increased in Indiana from <3% and 16% of annual cropland in 1990 to 7% and 38% in 1999, respectively. Simulated increases in C stocks of soils under continuous no tillage averaged about 0.5 tonnes ha^{-1} (0.22 tons ac^{-1}) for the state as a whole in 1999. The gain of soil C on reduced (i.e. 'moderate') tillage soils averaged about 0.38 tonnes ha^{-1} (0.17 tons ac^{-1}) across the state in 1999.

Examples of mean rates of soil C change for different tillage systems and selected soil types under corn-soybean rotations are shown in Figure 30. Rates are state averages over the period 1994-2004. Bars within columns show the range of values across all counties, which reflect past crop history and climatic differences in the state. Rates for moderate tillage and no tillage are averages for a ten-year period following conversion from intensive tillage. Also shown are projected rates of change with continuation of intensive tillage practices. In non-hydric (well-drained), intensively tilled soils (Figure 30 A), a low rate of increase in soil C is predicted, driven by increasing crop residue additions. Hydric (poorly drained) soils under conventional, intensive cultivation (Figure 30 B) are predicted to sequester slightly more C than the same non-hydric soils. This indicates that past drainage of hydric soils occurred long enough ago that it is having little effect on current decomposition rates and does not override the positive effects of increasing residue inputs.

In summary, estimates of the current rates of C change under the predominant crop (corn-soybean) rotation in Indiana are due largely to changes in tillage practices, but with an underlying influence of increasing crop residue inputs for all systems.

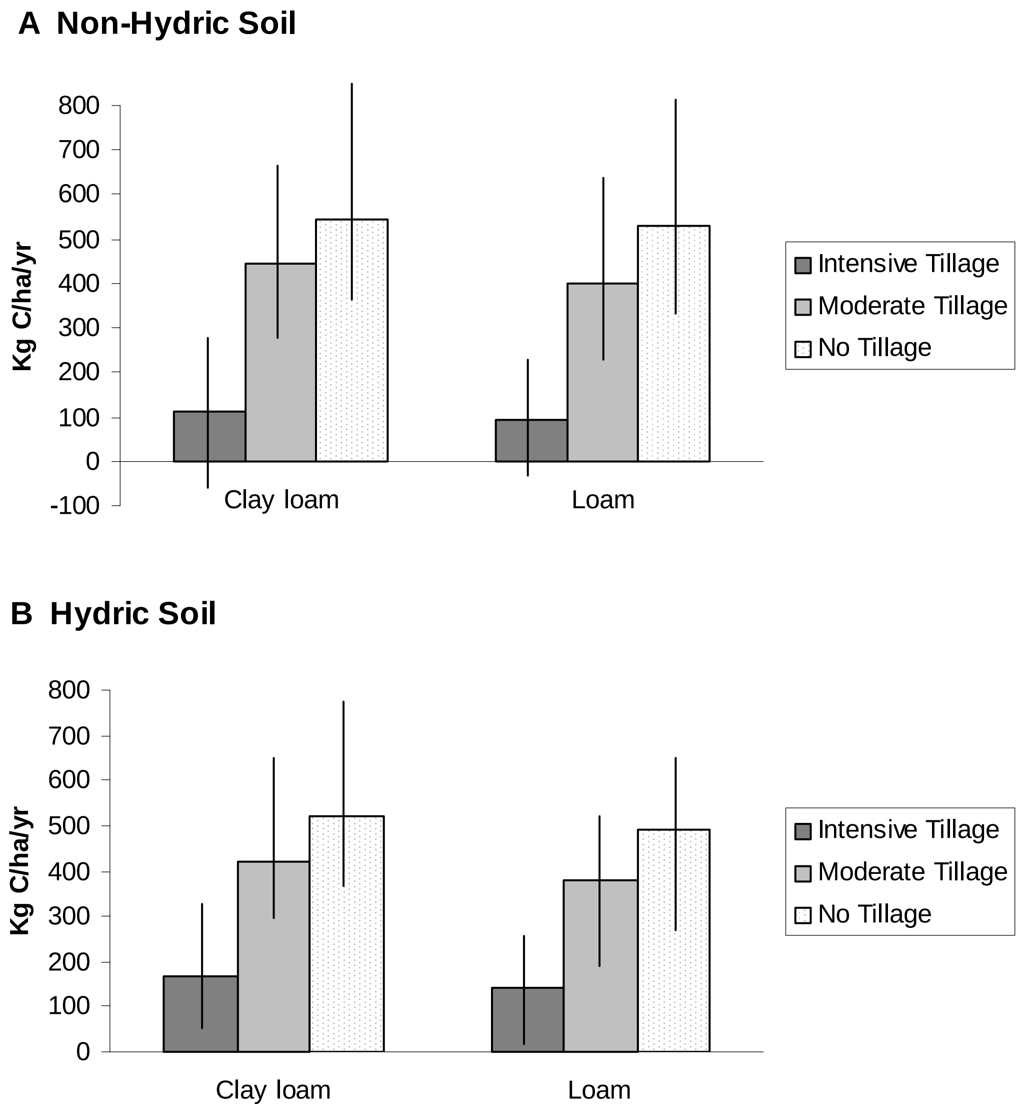


Figure 30: Changes in soil C across Indiana

Carbon sequestration rates predicted for Indiana soils with adoption of no tillage are in line with results from several long-term studies in the Corn Belt Region (Paustian et al., 2002). Recent regression based estimates of C accumulation under no-till from 15 long-term sites in the Midwest show average annual rates of 0.72 tonnes ha^{-1} (M. Eve, pers. comm.). Numerous other studies of tillage impacts illustrate the general trend of increased C sequestration from reducing or eliminating tillage, although rates vary considerably according to soil, climate, and management variables (Paustian et al., 1997b; West and Marland, 2001). In a few cases, negligible effects of tillage reduction on soil C have also been reported (e.g., Wander et al., 1998). The variability of the modeled response of soil C to adoption of no tillage is less than might be expected based on comparisons across different field studies with simulated rates of increase with no tillage adoption varying between about 0.5 and 0.7 tonnes ha^{-1} yr^{-1} (0.22 and 0.31 tons ac^{-1} yr^{-1}) across all soils. Additional sources of variability in response to tillage changes that can occur at a site-specific level, such as reduced productivity with unsuccessful no-till management, are not captured in the model application at county and state scales.

Conversion of annual cropland to CRP grasslands was estimated to yield 1990 C sequestration rates of about 1.0 tonnes ha^{-1} yr^{-1} (0.45 tons ac^{-1} yr^{-1}) and 1999 C sequestration rates of 0.9 tonnes ha^{-1} yr^{-1} (0.40 tons ac^{-1} yr^{-1}) averaged across the state. Simulated rates varied across counties and soilS, ranging from 1.0 to 1.8 tonnes ha^{-1} yr^{-1} (0.45 and 0.80 tons ac^{-1} yr^{-1}) for the first ten years after conversion and ranging from 0.6 to 1.5 tonnes ha^{-1} yr^{-1} (0.27 and 0.67 tons ac^{-1} yr^{-1}) for the second ten years after conversion. Non-hydric sands are sequestering at the lower rates while fine textured silty clays and silty clay loams are sequestering at the higher rates. The decrease in the C sequestration rate for the second ten years indicates that soils are approaching a new steady state condition, but still have the ability to sequester large amounts of C into the future. In comparison, Follett et al. (2001) estimated rates of C sequestration for 14 sites in the Central US, based on field sampling of paired CRP sites averaging 0.9 tonnes ha^{-1} yr^{-1} (0.40 tons ac^{-1} yr^{-1}). Sites in Iowa had the highest rates of C increase, ranging up to 4 tonnes ha^{-1} yr^{-1} (1.78 tons ac^{-1} yr^{-1}). Paustian et al. (2001) document several field studies of attributing increases in soil carbon with prairie restoration and application of CRP on former annual cropland, with values of around 1 tonnes ha^{-1} yr^{-1} (0.45 tons ac^{-1} yr^{-1}) for conditions similar to those in Indiana. As for reduced tillage effects, the model does not reflect the full range of variability in C change under CRP that would be expected through site-specific effects (e.g., poor stand establishment, high residual nutrient levels, pest effects), which cannot be captured in a regional assessment. It should also be noted that assumptions regarding nitrogen availability have a significant impact on the predicted response of CRP. For the present simulations, we assume that CRP planting included a legume component to help meet demands for nitrogen by the perennial vegetation. The same assumption was used for other grass conversions (e.g. grassed waterways, filter strips) given that these areas would likely receive significant N inputs from runoff and/or through the presence of legumes. Simulations with pure grass, with no fertilization and minimal pre-CRP residual nitrogen, were predicted to yield only about half of the rates reported here (unpublished data). Thus our estimates for CRP could be somewhat high if there are areas of CRP with significant nutrient limitations on productivity.

To estimate current changes in soil C storage under present management systems, we used the mean annual rates of C change for the simulated period for each management sequence X soil X county combination, multiplied by the area represented by that combination. Compiling all of the model-based estimates for managed cropland and grass with separate calculations for tree conversion, wetland restoration and cultivated organic soils, we estimate that Indiana soils are currently (i.e., based on 1990 and 1999 data) a net sink for CO_2, accumulating soil C at a rate of about 0.79 and 0.77 MMT per year, respectively (Table 6 and 7).

Table 6: 1990 summary of C sequestered by management system in Indiana

Management System	Metric Units			English Units		
	Hectare	Tonne C	Tonne CO_2	Acre	Ton C	Ton CO_2
Cropland	5,251,635	1,320,262	4,845,362	12,977,021	1,455,339	5,341,094
CRP/Grass Conv.	143,762	147,995	543,142	355,242	163,137	598,713
Tree/Wetland Conv.	6,336	3,123	11,461	15,657	3,443	12,636
Cult. Organic Soils	86,488	-681,524	-2,501,193	213,716	-751,251	-2,757,091
State Total	5,488,221	789,856	2,898,772	13,561,636	870,668	3,195,352

Table 7: 1999 summary of C sequestered by management system in Indiana

Management System	Metric Units			English Units		
	Hectare	Tonne C	Tonne CO_2	Acre	Ton C	Ton CO_2
Cropland	5,132,921	1,226,713	4,502,037	12,683,674	1,352,219	4,962,644
CRP/Grass Conv.	244,358	217,420	797,931	603,819	239,664	879,567
Tree/Wetland Conv.	24,455	11,458	42,051	60,429	12,630	46,352
Cult Organic Soils	86,488	-681,524	-2,501,193	213,716	-751,251	-2,757,091
State Total	5,488,222	774,067	2,840,826	13,561,638	853,262	3,131,472

The largest contributions to this C sequestration is attributed to the reduction in area under intensive tillage over the past 10 years (Table 8 and 9), and the conversion of formerly annually cropped area to perennial grasses through the CRP, as well as the increased installation of grass waterways, field buffers, filter strips, terrace walls and other conversion to grassed conservation practices (Table 6 and 7).

Table 8: 1990 total C sequestered in mineral soils by tillage system in Indiana

Tillage System	Metric Units			English Units		
	Hectare	Tonne C	Tonne CO_2	Acre	Ton C	Ton CO_2
Intensive Tillage	4,238,185	875,807	3,214,212	10,472,742	965,412	3,543,062
Moderate Tillage	855,001	360,628	1,323,505	2,112,745	397,524	1,458,913
No Tillage	158,449	83,827	307,645	391,534	92,403	339,119
State Total	5,251,635	1,320,262	4,845,362	12,977,021	1,455,339	5,341,094

Table 9: 1999 total C sequestered in mineral soils by tillage system in Indiana

Tillage System	Metric Units			English Units		
	Hectare	Tonne C	Tonne CO_2	Acre	Ton C	Ton CO_2
Intensive Tillage	2,688,857	254,113	932,595	6,644,284	280,112	1,028,011
Moderate Tillage	2,072,491	787,066	2,888,532	5,121,216	867,592	3,184,063
No Tillage	371,573	185,534	680,910	918,173	204,516	750,574
State Total	5,132,921	1,226,713	4,502,037	12,683,673	1,352,220	4,962,648

Based on 1990 and 1999 management data, Indiana mineral soils are a net C sink and sequester 1.47 and1.46 MMTC annually, respectively. More than one-half of Indiana's 5.13 million hectare (12.6 million acre) of cropland are still managed using conventional tillage practices, predominately under corn-soybean rotations. While some conventionally managed soils may be net sources of CO_2 (particularly artificially drained hydric soils), our analysis predicts an overall slow rate of increase of soil C for the conventionally managed cropland in the state due to increasing amounts of crop residues added to soil over the past three to four decades. Others (Cole et al., 1993; Allmaras et al., 2000) have also suggested that the general trends in crop productivity since WWII have changed agricultural soils from being a net C source to a net sink in the US. Tree conversion and wetland restoration is projected to represent a net carbon sink, but the overall effects on the C balance for the state are minor due to the relatively small 24,455 hectare (60,429 acre) of associated area. The cultivation of 86,488 hectare (213,716 acre) of organic soils is a major source of C to the atmosphere and is offsetting 46% of the benefits from all the other conservation practices that have been applied. These areas should be identified to document what land use and management decisions are presently occurring on them. The application of C conserving conservation practices can have a large impact on this potential source of C from the soil.

State summaries of annual C changes occurring on cropland are available from 1990-1999 in spreadsheet format and details are provided in Appendix C. Figures 31-33 show the associated areas and state totals of the effects of conservation practices on C sequestration. Again, the small area of organic cropland has a large impact on the C budget for the state. The COMET database provides each county with estimated amounts of C sequestered under various management practices. The database has been tailored to address the specific climate, soils, and current cropland management systems, and allows the user to project changes in soil C due to changes in crop and tillage practices (Appendix D).

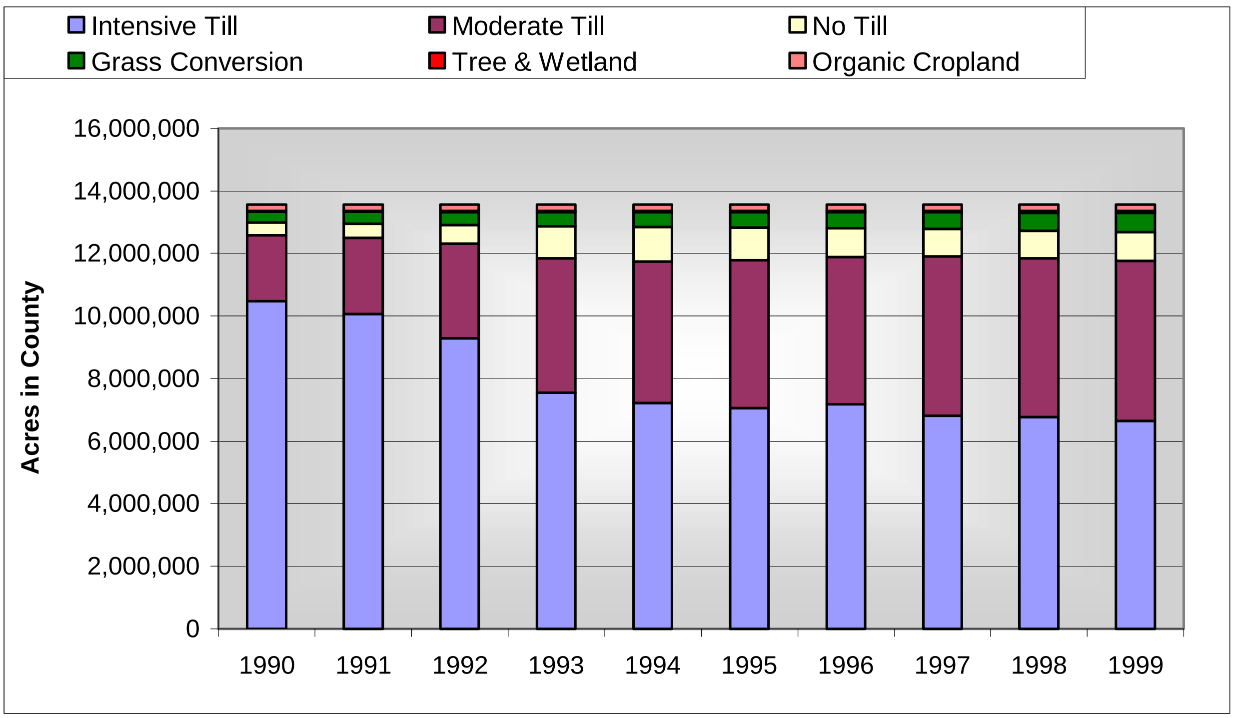


Figure 31: 1990-1999 areas for calculating C change due to conservation practices in Indiana

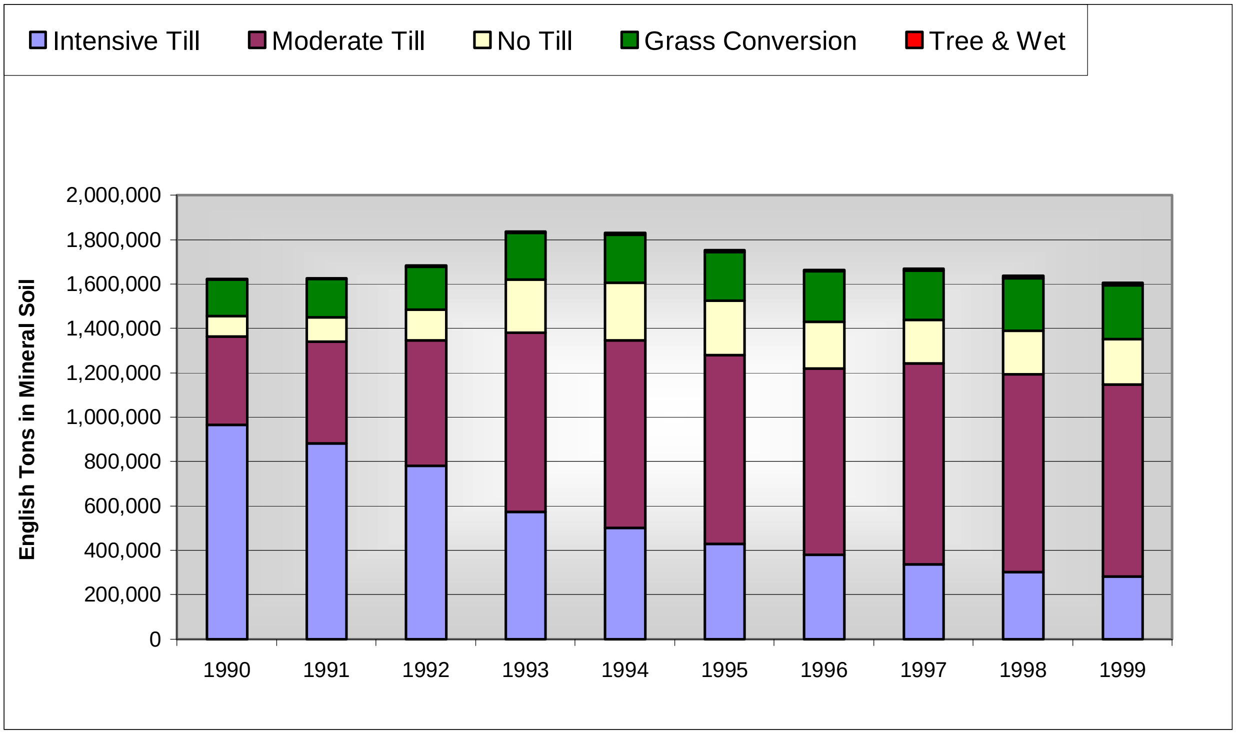


Figure 32: 1990-1999 C sequestration on mineral soils in Indiana

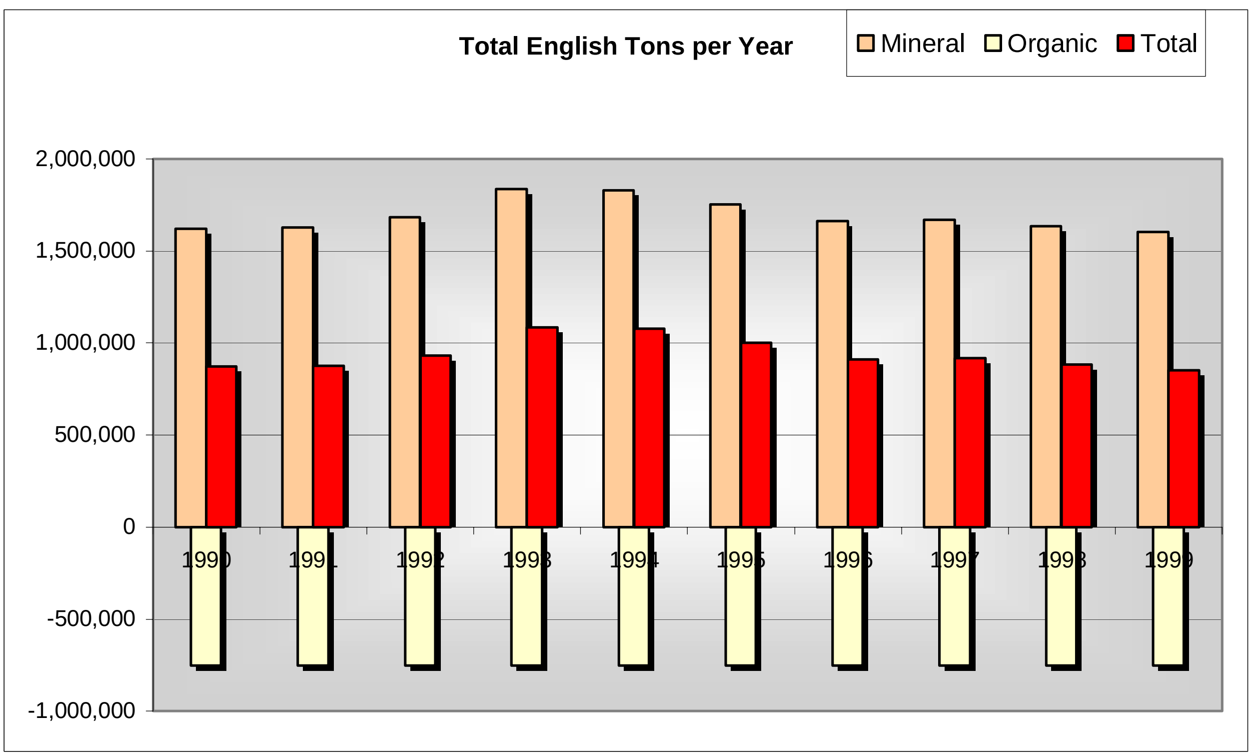
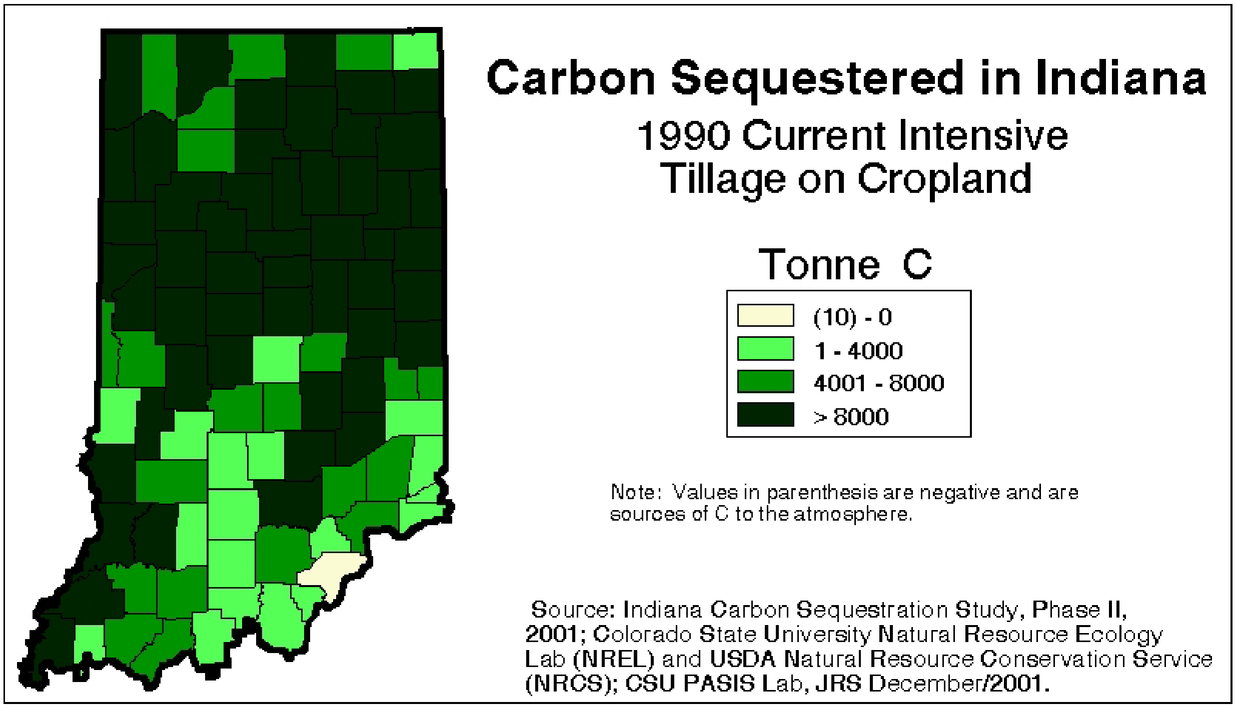


Figure 33: 1990-1999 state totals of C change on all soils in Indiana

County Summaries

The 1990 and 1999 effects of conservation are calculated for the effects on management due to tillage system, CRP, grass conversion, tree conversion and wetland reversion. These effects are summarized in the following figures and are also available for each county on the accompanying CD-ROM. Figures 34-36 show the distribution of the C sequestered in 1990 and 1999 throughout the state for the three types of tillage practices (intensive, moderate and no tillage). Land managers are changing intensive tillage systems to moderate or no tillage systems in most areas, but not all parts of the state. This movement between systems along with the associated C changes over time is showing that Indiana cropland soils are still providing a significant C sink to the atmosphere. Any effort to move the intensive tillage cropland into moderate tillage or no tillage will have significant effects on the amounts of C that can be sequestered in the soil.

The effects of CRP and grass conservation practices (grass waterways, terraces, grass seeding, etc.) in each county and the associated C being sequestered is based on a 25% legume-75% non-legume plant community, which provides a source of nitrogen due to the fixing capacity of legume plants. The CRP lands have been in grass for over 10 years and therefore the rates of C sequestration are declining. The CSRA data provided by the local land manager's detail the amount of additional grass conservation practices (grass waterways, terraces, grass seeding, etc.) that were installed between 1985 and 1999. Since many of these lands have been converted to perennial grass in the last 10 years, the rates of C sequestration are higher, but will decline the longer they are in perennial grass. Figure 37 shows the distribution of C sequestered in 1990 and 1999 due to CRP and grass conversions throughout the state. These lands provide valuable environmental benefits including cover for wildlife, reducing soil erosion and improving water quality. Should the land manager decide to return these lands to crop production, the Indiana COMET database can provide the effects of different management options to assess the changes in soil organic matter. The database will allow land managers to calculate the projected C sequestration over the next 20 years when these types of practices are installed.



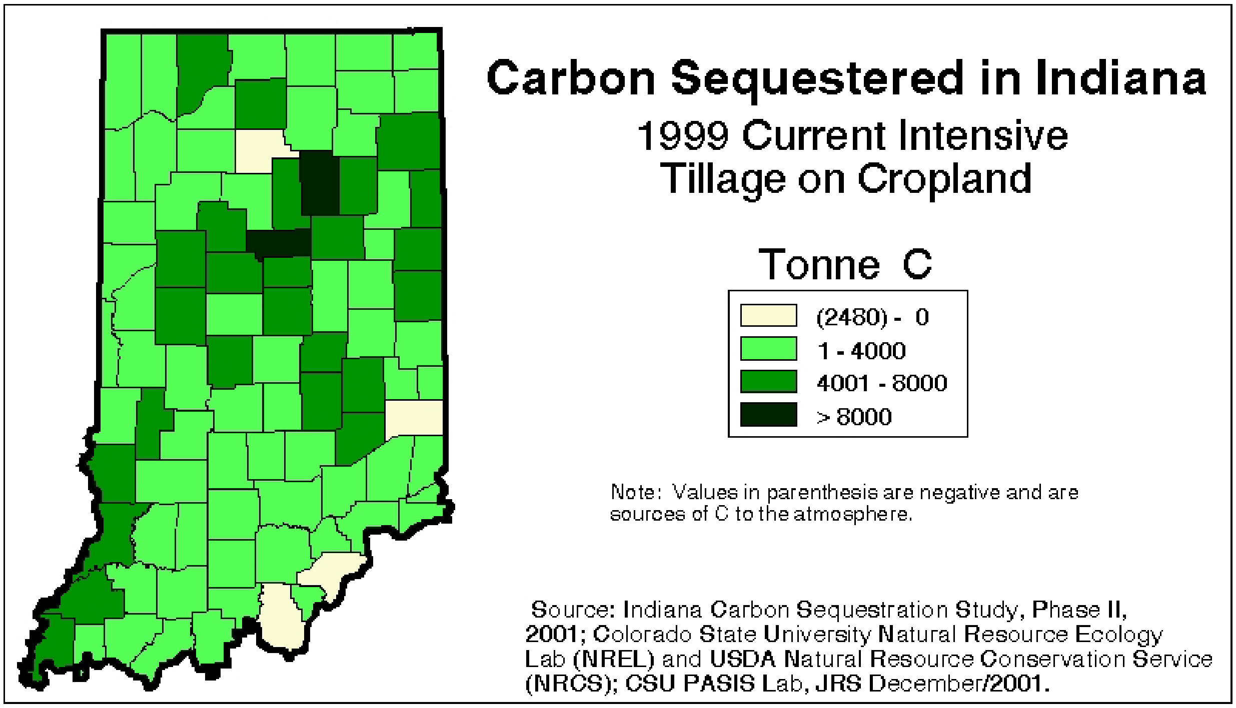
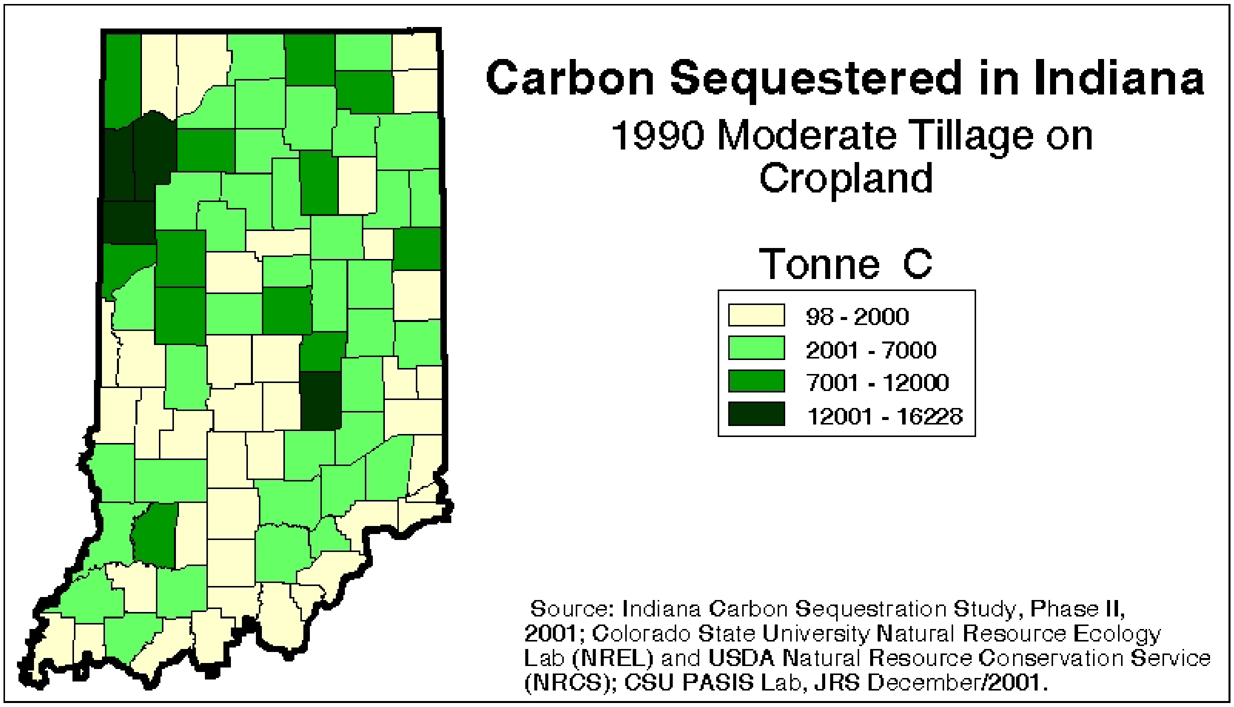


Figure 34: 1990 and 1999 C sequestered on intensive tillage cropland



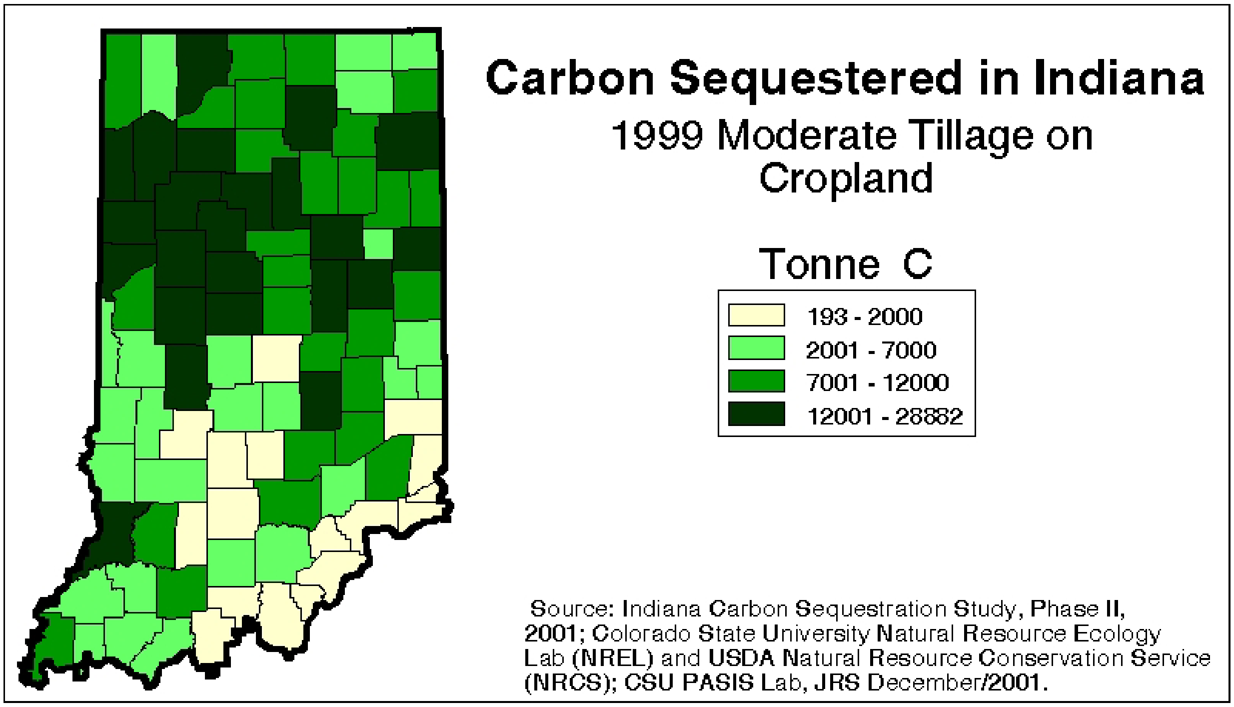
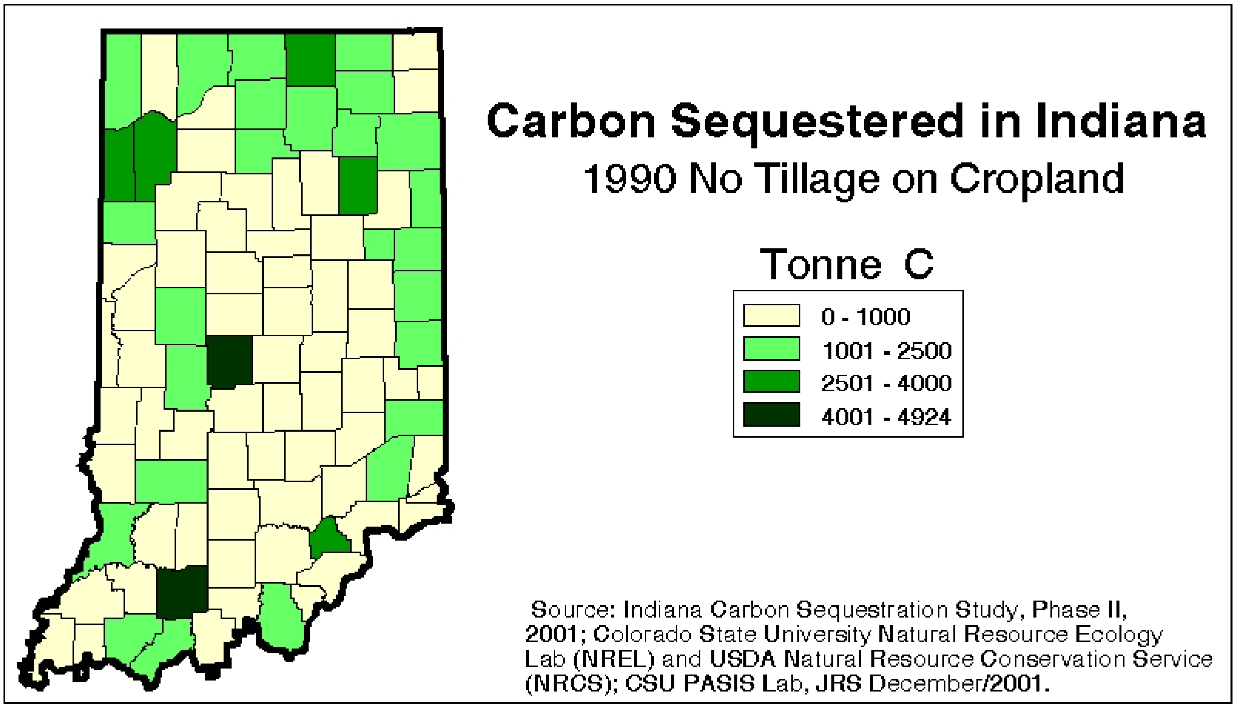


Figure 35: 1990 and 1999 C sequestered on moderate tillage cropland



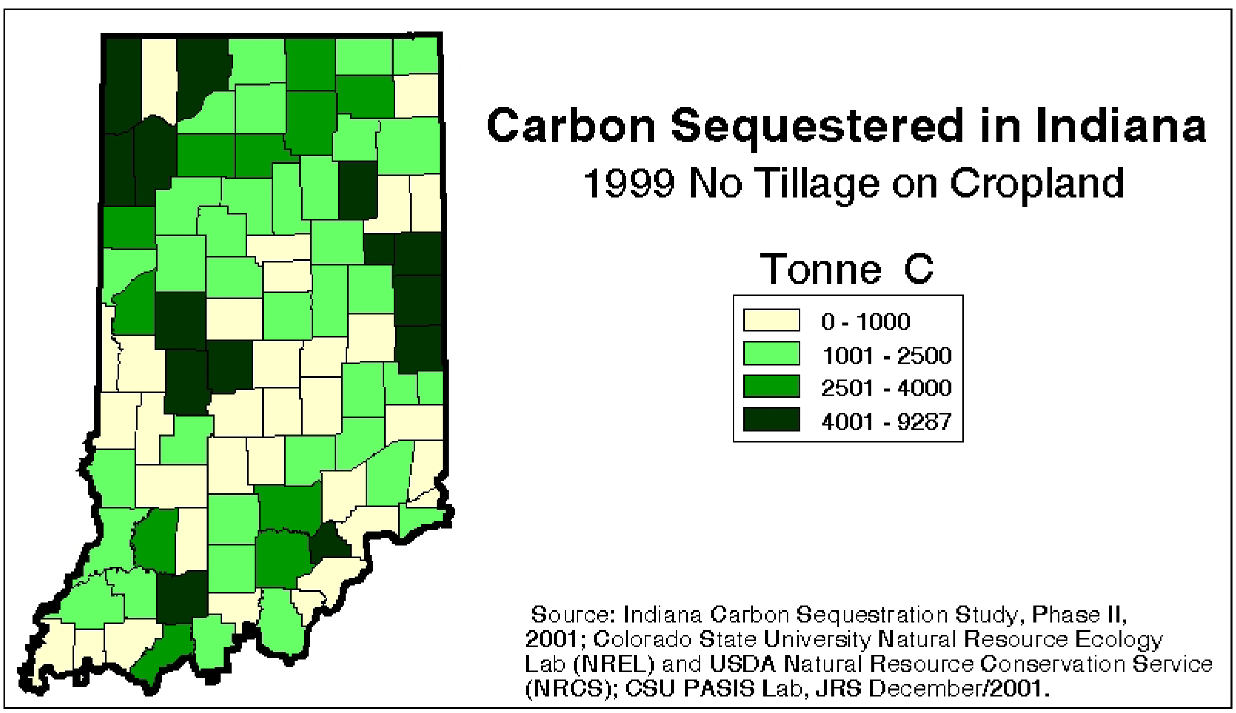
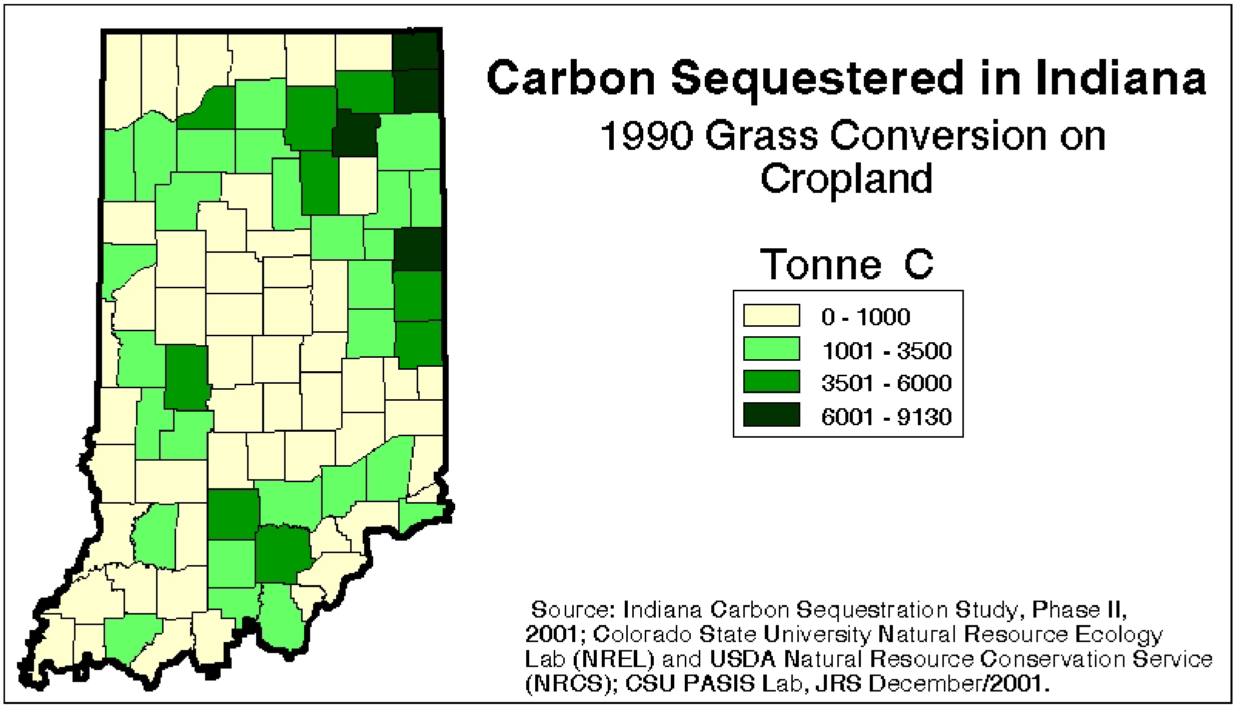


Figure 36: 1990 and 1999 C sequestered on no tillage cropland



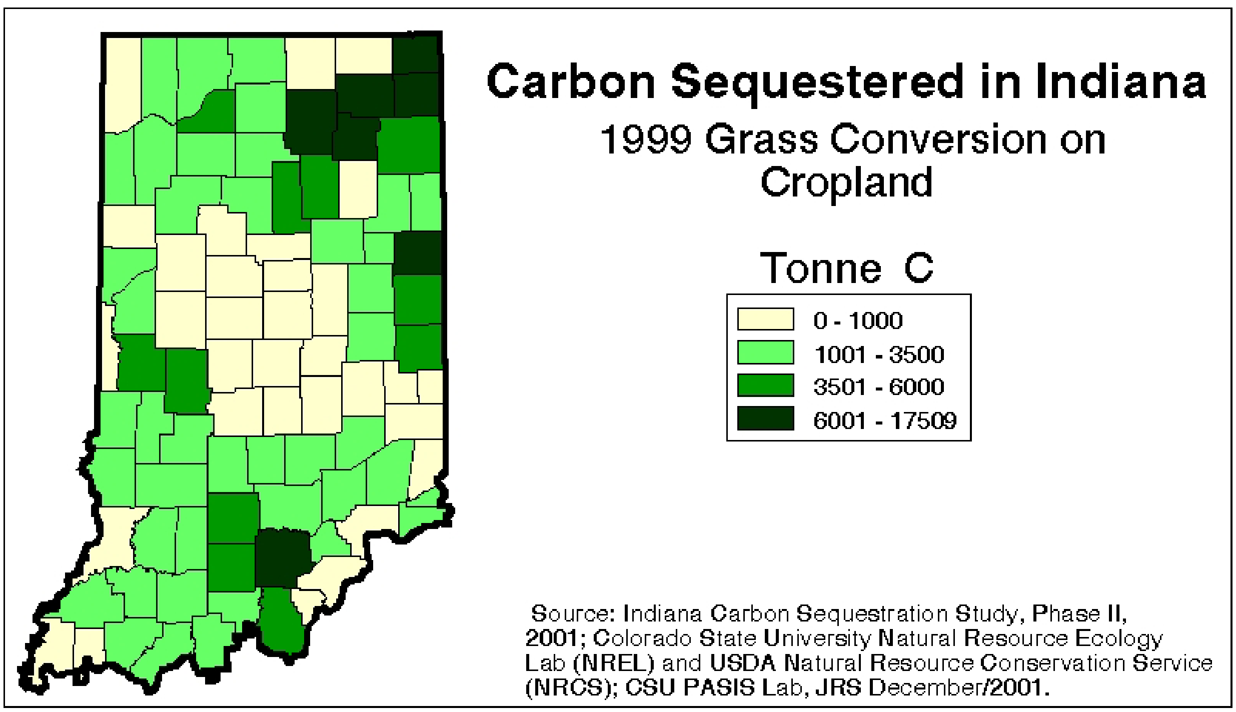
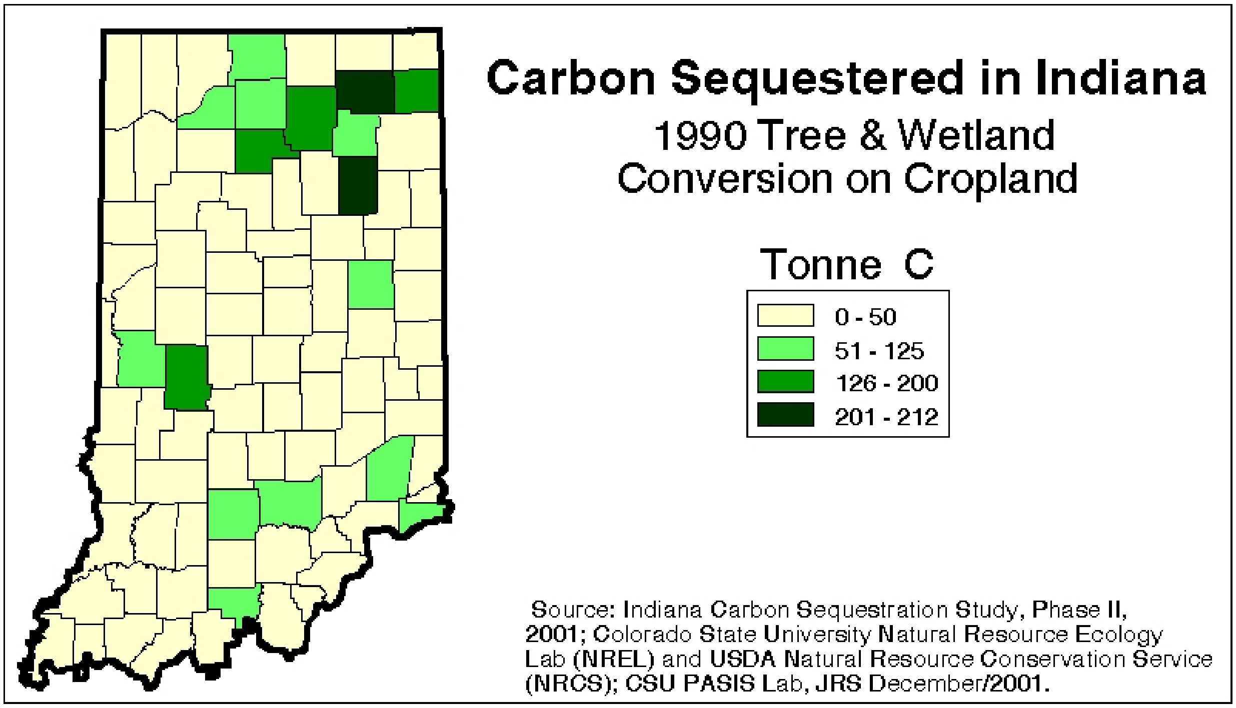


Figure 37: 1990 and 1999 C sequestered on cropland converted to grass

The C sequestration effects associated with tree conversions and wetland reversions are summarized in figure 38. These small areas need to be identified and accounted for which provides a more complete picture of how C sequestered due to tree conversions and wetland reversions throughout the state. Again, it needs to be noted that these areas do provide valuable cover for wildlife, reduce erosion and improve water quality.

Figure 39 summarizes the areas where C conserving practices are being adapted and the total 1990 and 1999 amounts of C being sequestered in mineral soils. These total amounts reflect the adoption of various conservation practices within each county. The higher rates of C sequestration in the northern half of the state reflects the adoption of moderate and no tillage systems as well as the installation of grass conservation practices. The lower rates in the southern part of the state reflect lower adoption rates of moderate and no tillage systems. It should also be noted that these are totals and the southern part of the state has less cultivated cropland in comparison to the northern half of the state. The southern part of the state does have significant amounts of area that has grass conservation practices applied. Figure 39 excludes emissions from the cultivation of organic soils.

Cultivation of organic soils is a major source of C to the atmosphere in Indiana. We have estimated the 1999 emission to be 681,524 tonnes C (751,251 tons C). This is based on the organic soils identified in the pre-release NRCS SURGO soils database and by personal communications with NRCS soil specialist in Indiana. 26 counties were identified containing organic soils and being cropped. The area in each of these counties is based on the GIS intersection of the soils information and the GAP cropland layer. These areas where then multiplied by the Midwestern North America coefficient of 7.88 tonnes C ha^{-1} yr^{-1} provided in Armentano and Verhoeven, 1990.



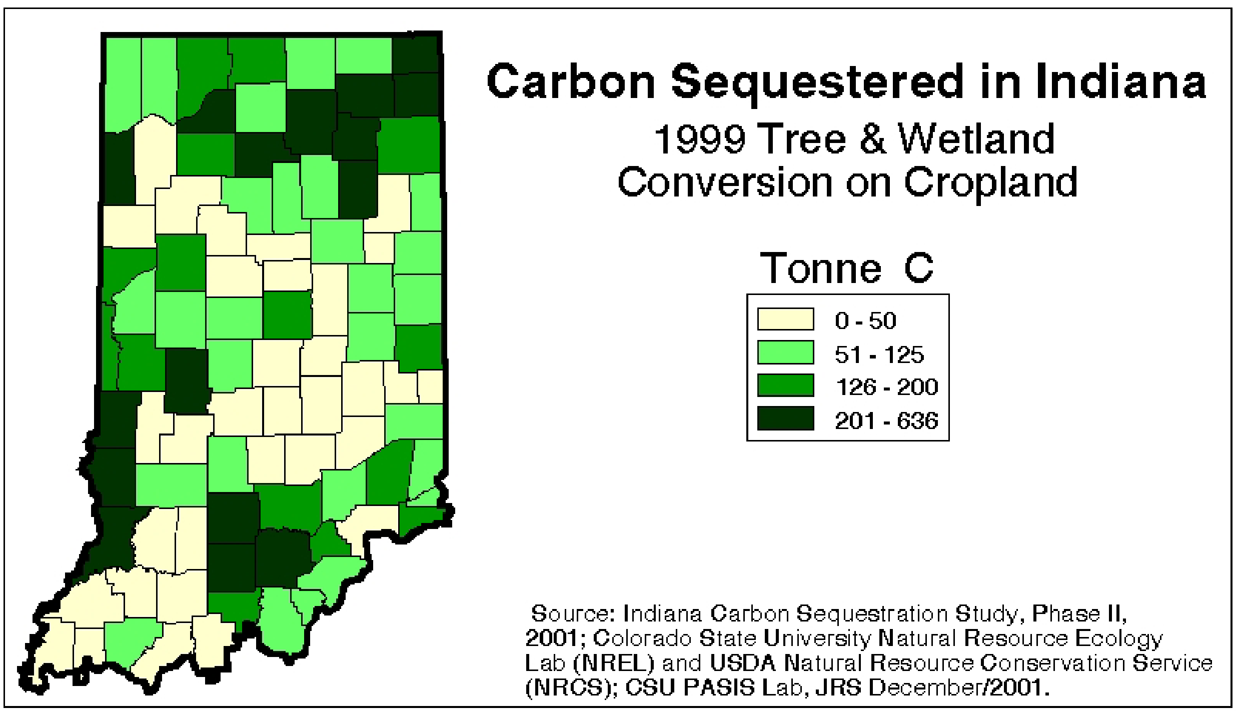
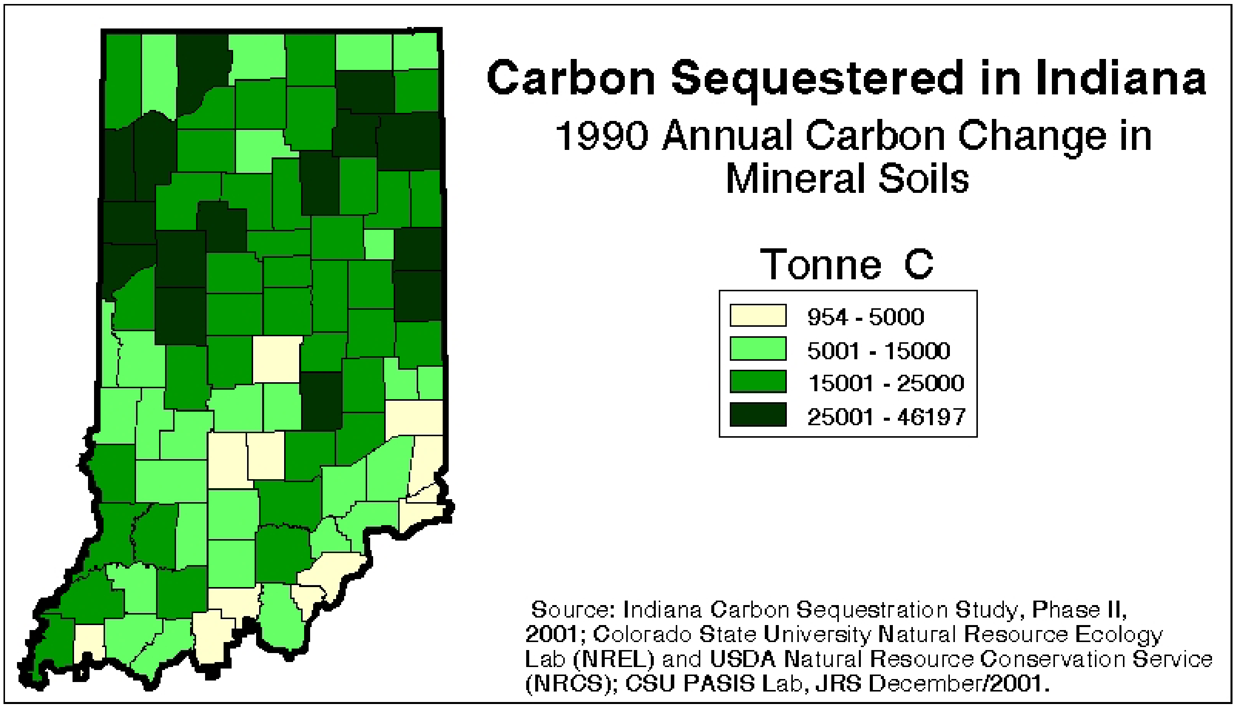


Figure 38: 1990 and 1999 C sequestered with tree conversions and wetland reversions



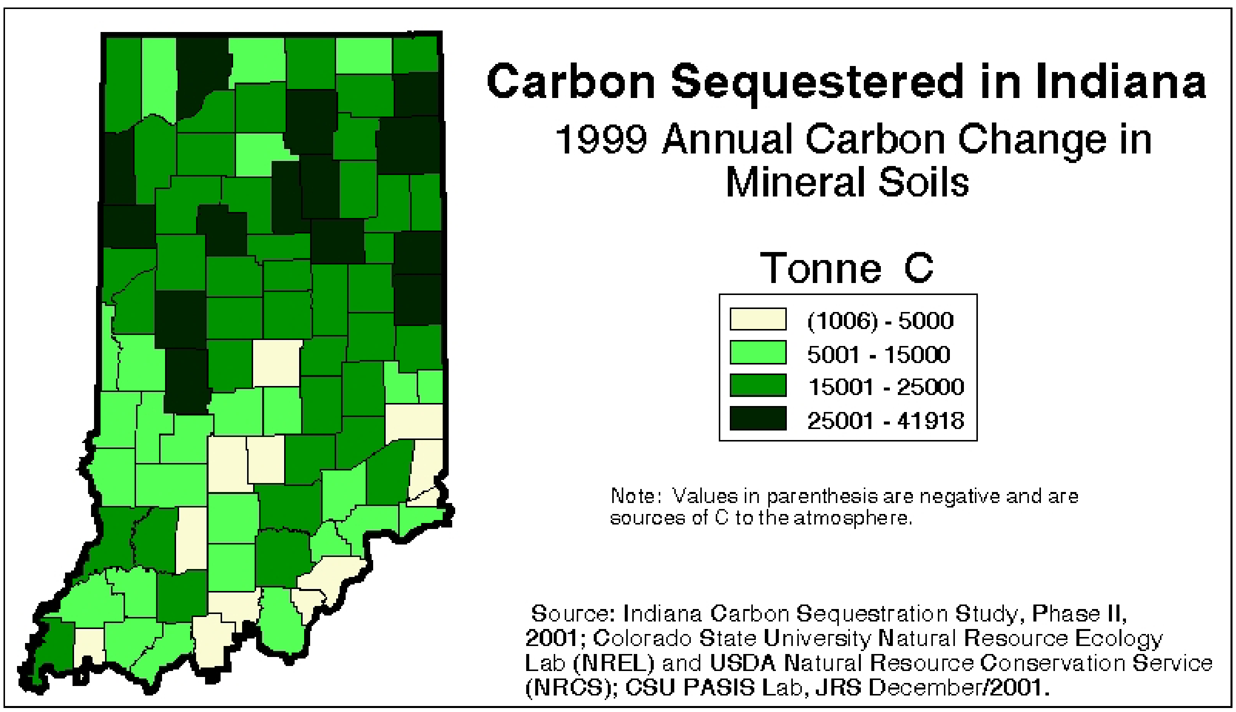


Figure 39: 1990 and 1999 C sequestered in mineral soils

All the identified counties are in the northern half of the state and the emissions for 1999 are shown in Figure 40. In some cases, the emissions are greater then all the sequestration occurring from the application of conservation practices. Figure 41-42 illustrates two very different counties, one with no organic soils being cultivated and a county with a large area of cultivated organic soils. In 1999, Gibson County identified no organic soils being cultivated and is sequestering 13,715 tonnes C (15,118 tons C). In 1999, Lagrange County identified 6,286 hectares (15,535 acres) of organic soils being cultivated and an emission of 49,540 tonnes C (54,608 tons). Lagrange County also is sequestering 9,109 tonnes C (10,041 ton C) from the application of conservation practices in 1999. The 1999 overall C budget for Lagrange County is an emission of 40,431 tonnes C (44,567 tons C) illustrating a significant source of C to the atmosphere. The spreadsheets outlined in Appendix C provide each counties C budgets from 1990-1999. Again, C conserving practices have the potential to reduce emissions from these soils.

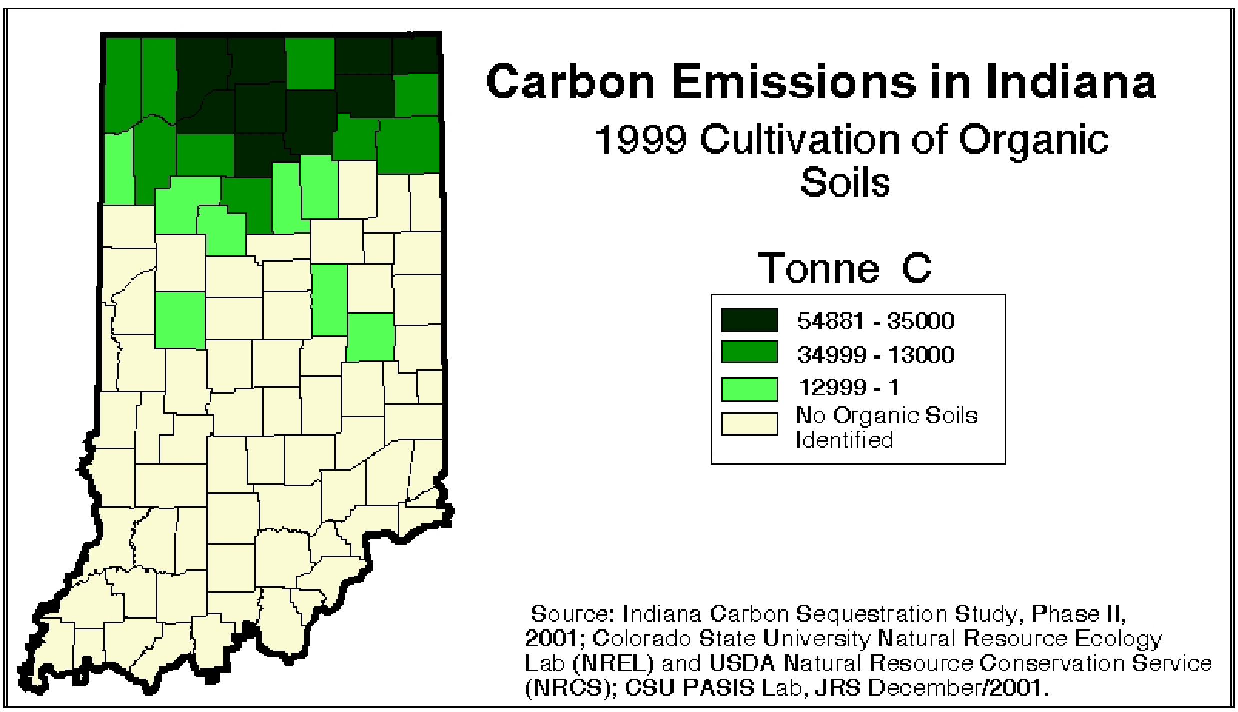


Figure 40: 1999 C emissions from the cultivation of organic soils

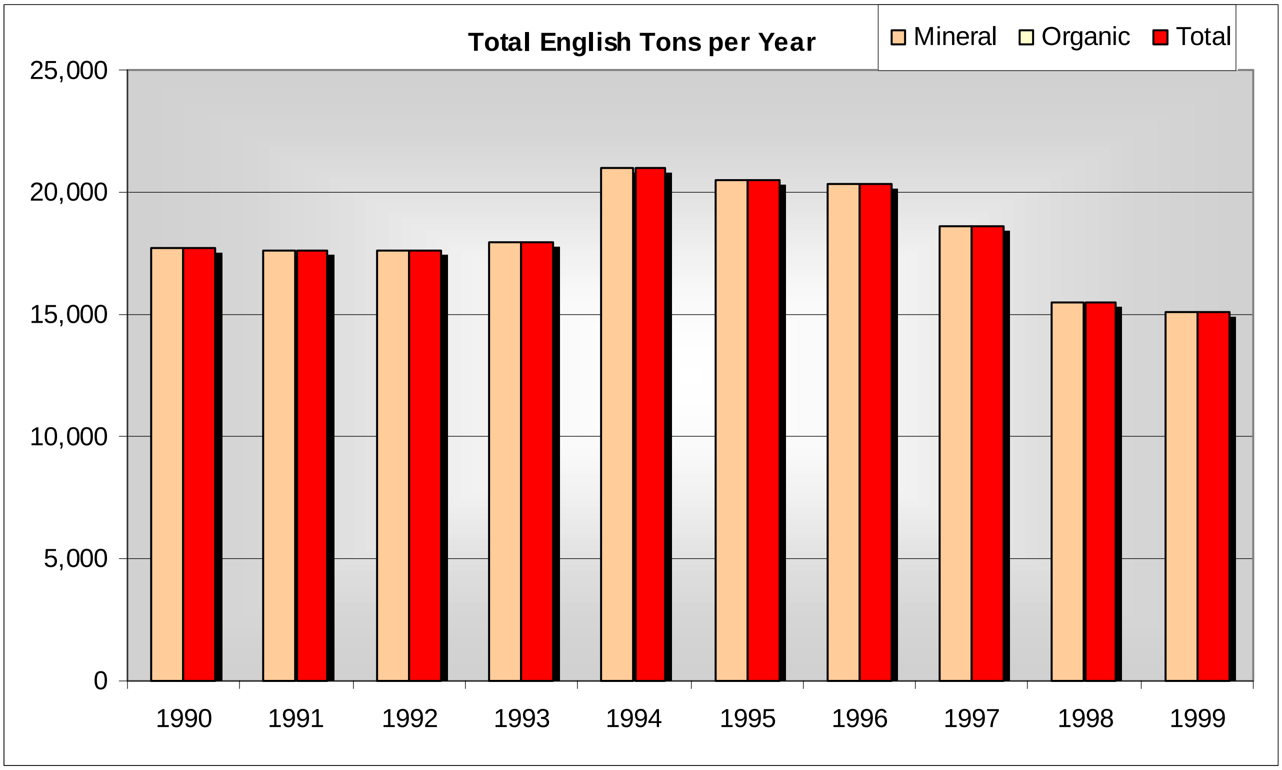


Figure 41: 1990-1999 C budget for Gibson County Indiana

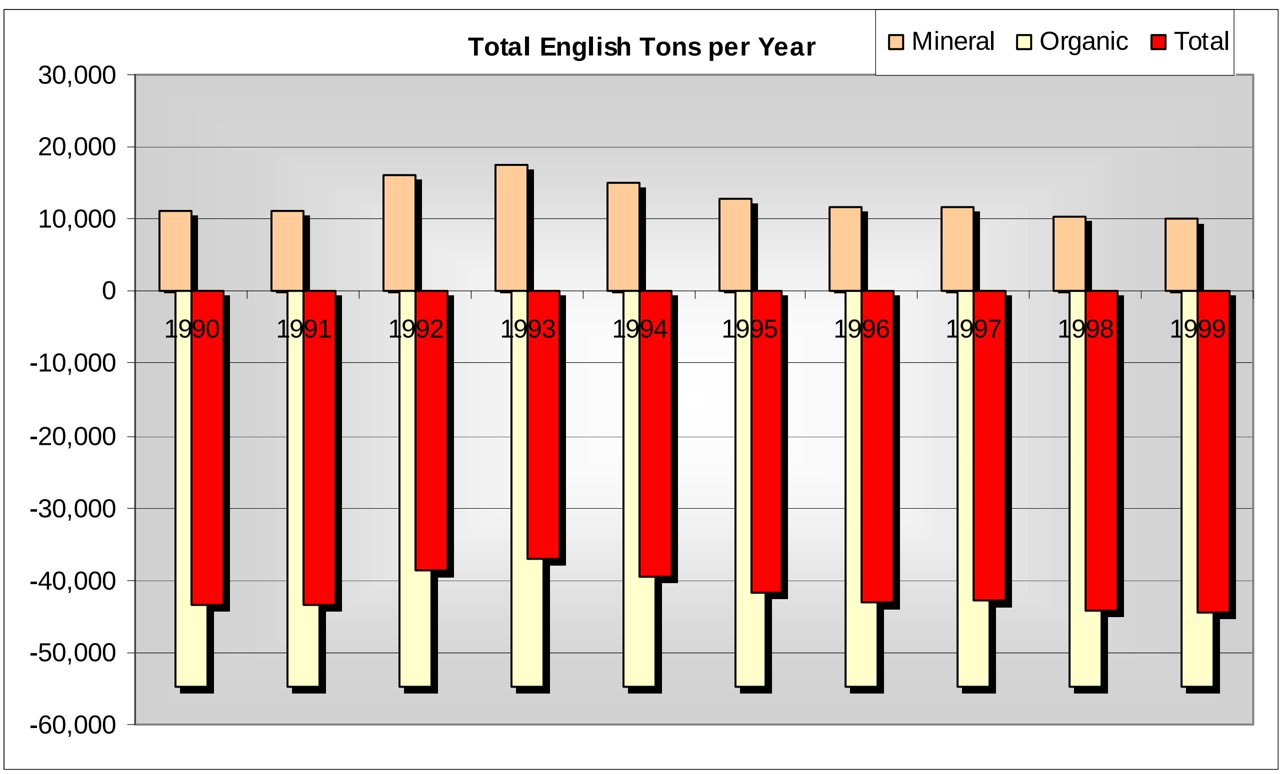


Figure 42: 1990-1999 C budget for Lagrange County Indiana

Databases

Results from over 800,000 model runs for each combination of climate (i.e. county average), soil type, and management sequence were compiled and entered into a distributed database that can be used to estimate current soil carbon changes, as well as potential C sequestration rates for the whole state. To provide a planning and assessment tool for land managers, model simulation results were organized into an Access (Microsoft Corp.) database with facilities to query and graph the results. The 'Indiana CarbOn Management Evaluation Tool (COMET)' database provides this interface with supporting user manual documentation (Appendix D) and illustrative presentation (enclosed CD-ROM). The user selects the desired county, major soil types within the county, and then selects from the menu crop rotations and tillage management sequences for each of two time periods (1974-1994 and 1994-2014). Two contrasting scenarios can be specified and displayed at the same time, allowing comparison of management alternatives. In addition, a table is produced showing the difference in C stock change (for both soil organic matter and crop residues) between scenarios. The data are configured to display the relative changes since the base year of 1974, but actual simulated C stocks are given in the accompanying data sheets.

Impacts

EPA estimates that Indiana's 1999 fossil fuel combustion emissions are 59.85 MMTCE (EPA 2001). The combustion of 1.45 short tons of coal or 424 U.S. gallons of gasoline will produce 1.0 short ton of C emissions in CO_2 (EPA, 2000). Mineral soils are sequestering 1.6 million short tons of C due to the effect of conservation practices on Indiana cropland and are removing the equivalent amount of CO_2 from the atmosphere that is produced from the combustion of 2.3 million tons, or 19,167 train cars of coal, or 0.68 billion gallons of gasoline. The cultivation of organic soils is a significant source of C back to the atmosphere and the net C sequestration occurring in Indiana is 774,067 tonnes. Excluding the impact from the cultivation of organic soils, decisions by land managers to use sound conservation practices on cropland are providing an offset of 2.7% of Indiana's 1999 fossil fuel emissions. If C is valued at $10 per tonne, Indiana cropland soils are providing a benefit of $16 million annually by current application of conservation practices by local land managers. With 49 percent of Indiana cropland using intensive tillage practices in 1999, any changes in management to move away from intensive tillage into moderate or no tillage systems will have the potential to sequester large amounts of C over time. The Indiana COMET database provides local land managers the ability to estimate these C changes due to management changes and allows them to assess the impact of these changes.

DOE Reporting

The U.S. Department of Energy (DOE) is responsible for the development and maintenance of a GHG database (DOE, 1992). DOE provides a method for local forms of government (i.e., conservation districts) to report sources and/or sinks of GHGs, and the local Conservation Districts in Indiana agreed to report the amounts of C sequestrated by the installation of agricultural conservation practices to DOE. Voluntary reporting of GHGs using the DOE Energy Information Administration EIA, 1605(b) process allows conservation districts to report the benefits of applying conservation practices.

The calculated 1999 C sequestered, or the CO_2 being removed from the atmosphere, is shown in Table 10. These values are based on the entire analysis described, using the best available data and the local knowledge of land managers. This is the data that each conservation district reports using 1605(b). Data for each year from 1990-1999 is available on the attached CD-ROM using spreadsheets and reflects each county value. Both SI and English units are shown to help convey the results to the conservation partnership in Indiana.

Table 10: 1999 C Sequestered for each county in Indiana

County	Metric Units			English Units		
	Hectare	Tonne C	Tonne CO_2	Acre	Ton C	Ton CO_2
Adams	73426	20282	74433	181440	22357	82049
Allen	105588	13676	50191	260913	15075	55326
Bartholomew	59002	15082	55352	145798	16626	61016
Benton	97296	31787	116659	240425	35039	128594
Blackford	34600	14916	54743	85498	16442	60344
Boone	95308	17929	65798	235510	19763	72529
Brown	4916	2561	9397	12147	2822	10358
Carroll	85107	21785	79949	210305	24013	88129
Cass	87578	3432	12595	216410	3783	13884
Clark	27481	2476	9087	67907	2729	10017
Clay	50385	11914	43724	124503	13133	48197
Clinton	98986	19757	72508	244600	21778	79926
Crawford	4422	2710	9946	10927	2987	10963
Daviess	67053	18483	67833	165691	20374	74773
Dearborn	12387	2036	7473	30608	2245	8238
Decatur	68634	18272	67058	169599	20141	73919
DeKalb	73403	12185	44718	181383	13432	49294
Delaware	75158	18116	66487	185719	19970	73289
Dubois	41461	17707	64986	102452	19519	71635
Elkhart	79547	3743	13737	196566	4126	15142
Fayette	32843	8130	29838	81158	8962	32891
Floyd	5875	1055	3873	14519	1163	4269
Fountain	72333	19211	70506	178740	21177	77720
Franklin	37190	-1006	-3692	91898	-1109	-4070
Fulton	79832	-31025	-113861	197269	-34199	-125510
Gibson	74107	13715	50334	183124	15118	55483
Grant	90188	24814	91067	222860	27353	100384
Greene	42181	10935	40131	104231	12054	44237
Hamilton	61545	15524	56975	152080	17113	62804
Hancock	64244	14281	52409	158750	15742	57772
Harrison	22913	8234	30218	56620	9076	33310
Hendricks	79363	18766	68870	196110	20685	75916
Henry	78699	14500	53216	194469	15984	58661
Howard	65314	16824	61743	161396	18545	68059
Huntington	82209	21747	79813	203144	23972	87979
Jackson	59179	18710	68667	146235	20625	75692
Jasper	119512	-5452	-20008	295322	-6010	-22055
Jay	78287	41158	151051	193451	45369	166506
Jefferson	33340	5610	20587	82385	6183	22693
Jennings	40468	8558	31409	99999	9434	34622
Johnson	45003	8159	29942	111205	8993	33006
Knox	94373	17482	64159	233202	19271	70723
Kosciusko	106103	-20021	-73479	262188	-22070	-80996
Lagrange	68951	-40431	-148381	170383	-44567	-163563
Lake	63631	-6250	-22937	157235	-6889	-25284
LaPorte	93696	-19067	-69976	231527	-21018	-77135
Lawrence	21527	9368	34379	53194	10326	37896
Madison	92229	17251	63312	227904	19016	69789

County	Metric Units			English Units		
	Hectare	Tonne C	Tonne CO_2	Acre	Ton C	Ton CO_2
Marion	11962	2981	10940	29559	3286	12059
Marshall	90480	-29068	-106679	223582	-32042	-117594
Martin	12557	4749	17427	31030	5234	19210
Miami	78922	12317	45202	195022	13577	49826
Monroe	9269	3078	11296	22904	3393	12452
Montgomery	102723	32565	119512	253835	35896	131739
Morgan	32609	7729	28364	80579	8519	31266
Newton	85008	19953	73227	210059	21994	80719
Noble	77027	-26429	-96993	190338	-29132	-106916
Ohio	4317	2063	7572	10668	2274	8347
Orange	21224	8557	31405	52445	9433	34618
Owen	19122	6671	24482	47251	7353	26986
Parke	52507	12379	45432	129747	13646	50080
Perry	8344	2757	10119	20619	3039	11155
Pike	30068	8523	31278	74299	9395	34478
Porter	64757	-16116	-59146	160018	-17765	-65197
Posey	73090	15003	55063	180611	16539	60696
Pulaski	94136	-7025	-25780	232615	-7743	-28418
Putnam	59870	27708	101688	147943	30543	112092
Randolph	103169	25725	94411	254936	28357	104070
Ripley	48653	15084	55359	120225	16627	61023
Rush	89966	17809	65358	222311	19631	72044
Scott	18768	9217	33827	46377	10160	37288
Shelby	87500	21648	79448	216217	23863	87576
Spencer	50060	8840	32444	123701	9745	35764
St Joseph	76701	-37192	-136495	189531	-40997	-150460
Starke	55843	-29786	-109315	137992	-32833	-120499
Steuben	54937	-17024	-62479	135753	-18766	-68871
Sullivan	63201	10396	38154	156173	11460	42058
Switzerland	12307	5137	18852	30412	5662	20781
Tippecanoe	94552	22583	82880	233643	24894	91359
Tipton	63516	15974	58623	156953	17608	64621
Union	27455	9277	34047	67842	10226	37531
Vanderburgh	21500	3711	13621	53127	4091	15014
Vermillion	36863	7452	27348	91090	8214	30146
Vigo	49848	7336	26925	123176	8087	29679
Wabash	88594	20812	76379	218920	22941	84193
Warren	69048	21172	77701	170621	23338	85651
Warrick	32480	8563	31427	80260	9439	34642
Washington	42580	18294	67139	105217	20166	74008
Wayne	60472	18856	69203	149431	20786	76283
Wells	84510	18824	69083	208828	20750	76151
White	112038	15204	55798	276854	16759	61506
Whitley	68798	8131	29842	170005	8963	32895

C Sequestration Rates For Conservation Practices

The Indiana COMET database allows land managers to quantify soil C changes for present land management systems and shows what effects various conservation treatments will have on soil C changes. Table 11 provides an example of inputs needed to quantify changes in soil C due to management changes for a corn-soybean crop rotation, and also includes cropland converted to CRP. This example is for a non-hydric, loam (L) soil in Adams County with a base history of corn-bean-wheat.

Table 11: Example query methods for the Indiana COMET database

Option	Database Description	System A	System B
1	1st Rotation, 1975-1994:	A	A
	1st Rotation Tillage Practices:	intensive tillage	intensive tillage
	2nd Rotation, 1995-2014:	A	A
	2nd Rotation Tillage Practices:	intensive tillage	moderate tillage
2	1st Rotation, 1975-1994:	A	A
	1st Rotation Tillage Practices:	intensive tillage	intensive tillage
	2nd Rotation, 1995-2014:	A	A
	2nd Rotation Tillage Practices:	intensive tillage	no tillage
3	1st Rotation, 1975-1994:	A	A
	1st Rotation Tillage Practices:	intensive tillage	intensive tillage
	2nd Rotation, 1995-2014:	A	B
	2nd Rotation Tillage Practices:	intensive tillage	no tillage
4	1st Rotation, 1975-1994:	A	A
	1st Rotation Tillage Practices:	intensive tillage	intensive tillage
	2nd Rotation, 1995-2014:	A	C
	2nd Rotation Tillage Practices:	intensive tillage	no tillage
5	1st Rotation, 1975-1994:	D	D
	1st Rotation Tillage Practices:	int(10) no (10)	intensive (10 yrs) then no tillage (10 yrs)
	2nd Rotation, 1995-2014:	B	A
	2nd Rotation Tillage Practices:	no tillage	intensive tillage
6	1st Rotation, 1975-1994:	D	D
	1st Rotation Tillage Practices:	int(10) no (10)	intensive (10 yrs) then no tillage (10 yrs)
	2nd Rotation, 1995-2014:	B	A
	2nd Rotation Tillage Practices:	no tillage	moderate tillage
7	1st Rotation, 1975-1994:	D	D
	1st Rotation Tillage Practices:	int(10) no (10)	intensive (10 yrs) then no tillage (10 yrs)
	2nd Rotation, 1995-2014:	B	A
	2nd Rotation Tillage Practices:	no tillage	no tillage

Option	Database Description	System A	System B
8	1st Rotation, 1975-1994:	E	E
	1st Rotation Tillage Practices:	int(10) no (10)	intensive (10 yrs) then no tillage (10 yrs)
	2nd Rotation, 1995-2014:	C	A
	2nd Rotation Tillage Practices:	no tillage	intensive tillage
9	1st Rotation, 1975-1994:	E	E
	1st Rotation Tillage Practices:	int(10) no (10)	intensive (10 yrs) then no tillage (10 yrs)
	2nd Rotation, 1995-2014:	C	A
	2nd Rotation Tillage Practices:	no tillage	moderate tillage
10	1st Rotation, 1975-1994:	E	E
	1st Rotation Tillage Practices:	int(10) no (10)	intensive (10 yrs) then no tillage (10 yrs)
	2nd Rotation, 1995-2014:	C	A
	2nd Rotation Tillage Practices:	no tillage	no tillage

A=corn-soybean; B=CRP 20 yrs (100% grass); C=CRP 20 yrs (25% legume,75% grass); D=corn-soybean 10 yrs-CRP 10 yrs (100% grass); E=corn-soybean 10 yrs-CRP 10 yrs (25% legume, 75% grass); int(10) no (10)= intensive (10 yrs) then no tillage (10 yrs)

Table 12 summarizes the soil C changes due to management options as outlined in Table 11. Soil C increases as tillage disturbances decrease in options 1 and 2. Options 3 and 4 show increases in soil C when cropland is converted to permanent grass, such as buffers and grass waterways. Both grass options illustrate that by combining legumes and grasses together, the soil C increase can be increased. The CRP example also includes both grass options. If legumes were seeded when the CRP was established, then the 25% legume, 75% grass option should be used. Options 5-7 reflect what happens when CRP lands, which were planted using 100% grasses, are returned to crop production. When a crop rotation of corn-soybean using an intensive tillage system is used, soil C decreases by 0.15 tonnes ha^{-1} yr^{-1} (0.07 tons ac^{-1} yr^{-1}). A moderate tillage system shows a small increase of 0.27 tonnes ha^{-1} yr^{-1} (0.12 tons ac^{-1} yr^{-1}), while a no tillage system is increasing soil C at a rate of 0.44 tonnes ha^{-1} yr^{-1} (0.20 tons ac^{-1} yr^{-1}). Options 8-10 reflect the result of CRP lands, planted to 25% legumes and 75% grasses, returned to crop production. When a crop rotation of corn-beans using an intensive tillage system is used, soil C decreases by 1.41 tonnes ha^{-1} yr^{-1} (0.63 tons ac^{-1} yr^{-1}). A moderate tillage system shows a decrease of 0.90 tonnes ha^{-1} yr^{-1} (0.40 tons ac^{-1} yr^{-1}), while a no tillage system shows a decrease of soil C of 0.71 tonnes ha^{-1} yr^{-1} (0.32 tons ac^{-1} yr^{-1}). These results demonstrate how the database and management decisions can increase or decrease soil C and how land managers can address local conditions for cropping, tillage, soils, and management systems desired by the customer.

Table 12: C sequestration rates for the first ten years after a management change

Option	Metric Units		English Units	
	Tonne C ha^{-1}	Tonne C ha^{-1} yr^{-1}	Ton C ac^{-1}	Ton C ac^{-1} yr^{-1}
1	3.5	0.35	1.6	0.16
2	5.0	0.50	2.2	0.22
3	4.0	0.40	1.8	0.18
4	13.2	1.32	5.9	0.59
5	-1.5	-0.15	-0.7	-0.07
6	2.7	0.27	1.2	0.12
7	4.4	0.44	2.0	0.20
8	-14.1	-1.41	-6.3	-0.63
9	-9.0	-0.90	-4.0	-0.40
10	-7.1	-0.71	-3.2	-0.32

Presentations, Papers And Resulting Public Awareness

Through the efforts of the researchers, conservation partners, and NACD, various press articles and scientific papers have been published on the Indiana C Storage Project. A compilation of these is attached in Appendix E. These articles are intended to inform the public, not only in Indiana but throughout the U.S., of the C sequestration issue and the implications of this project. They also succeed in illustrating how local people can become a part of the debate, and how local land managers can assume a significant role in the development of science and policy.

Scientists from NREL and NRCS have made presentations in the US and internationally concerning the project and its findings and are summarized in Appendix E. These presentations were made to local land managers, state conservation partners, national policy leaders, and scientific audiences at national and international conferences. Publishing in peer reviewed scientific journals facilitates the advancement of science in C modeling and our ability to quantify rates of carbon sequestration. Several papers are currently under preparation, and will be submitted to various publishing venues. These papers describe and analyze the methods and results of the Indiana project and comprise the basis for further research on soil C and GHGs.

Data Availability

All the data used in the analysis is archived at CSU-NREL and available by request. This includes GIS coverage's, a copy of the Century model, Century input files and CSRA relational database. The enclosed CD-ROM contains this report, the Access database 'Indiana CarbOn

Management Evaluation Tool (COMET)' database which allows the user to query the simulated results by county, soil texture/hydric characteristics, cropping systems and tillage intensity and the spreadsheet summaries detailing the total C changes attributed to conservation practices from 1990-1999. The county GAP images are also enclosed on the CD-ROM as post script files and can be printed to any post script printer.

Recommendations For Further Work

Our assessment approach was heavily model-based, utilizing a wide range of geographic databases and county-level statistics, complemented by new information on land use and management gathered using the CSRA. The existing network of long-term experiments provides a solid basis for understanding the influence of various management practices on soil carbon dynamics and are invaluable in assessing the validity of assessment models. However, the establishment of on-farm monitoring locations, where soil C changes could be directly measured over time, would enhance the present quantification approach. It would provide additional information on changes for soils and practices that are at present underrepresented in the existing field experimental network, plus it would provide information reflecting actual on-farm conditions, rather than those of research experimental plots. The feasibility and success of such a monitoring component has been demonstrated in the Canadian Prairie Provinces project (B. McConkey, pers. comm.) and it should be possible to begin establishing such monitoring plots in conjunction with other on going activities such as soil survey. Key attributes of monitoring sites are that they be precisely georeferenced (e.g. with GPS and buried plot markers) to enable resampling at the precise location and that information on the management practices used on the site are registered. The potential exists for collaborating with farmer and conservation associations to begin developing such a network in Indiana. Information gathered from such a network could be used to further test and refine the model-based assessments.

The potential effects of soil erosion on CO_2 emissions and C sequestration were not included in our analysis and the influence of erosion on regional soil C balance represents an area requiring further study. Clearly, erosion can have a major effect on carbon stocks at a particular location through the transport and redistribution of soil and its associated organic matter. However the impacts will vary depending on whether the location is an erosional or depositional surface. At present, there is considerable debate as to the net effects of erosion on soil C sequestration at the landscape or regional scale. On the one hand, erosion can break up soil aggregate structures and expose protected organic matter to enhanced decomposition, which would lead to increased CO_2 emissions. On the other hand, deposition and burial of soil in lower parts of the landscape (or in lake and reservoir sediments) could result in decreased CO_2 emissions on a landscape basis. Both effects may be significant, however, there is very little information available to judge which process is dominant or whether the effects cancel out. For many of the conservation practices dealt with in our analysis (e.g. CRP, grass conversions, no-till) erosion rates are likely to be very low and thus an explicit treatment of erosion may not be critical. However, further research on carbon dynamics at the landscape scale is merited to address this issue. In any case, there is no question that the benefits of conservation practices for reducing soil erosion are extremely important, regardless of the impacts of erosion on soil C sequestration.

The focus of the assessment has been on strategies to mitigate CO_2 increase, through carbon sequestration. However, the resource and land use/land management data compiled in this study form a solid basis for more comprehensive estimates of greenhouse gas emissions and mitigation potential, including estimating fluxes of N_2O and CH_4 fluxes associated with cropping practices and CO_2 emissions associated with agricultural inputs, such as fuel use and fertilizer manufacture. Both standard accounting approaches such as the IPCC inventory methodology and dynamic models of N_2O and CH_4 emissions can be applied using the resource data and other information collected in the CSRA. Significant options exist for agricultural mitigation of non-CO_2 greenhouse gases and assessment of these potentials would be greatly facilitated by the data and information that have been compiled in the present project.

The use of agriculture products and residues as a source of renewable fuels is attracting interest from public and private entities. This analysis along with the supporting databases can provide useful information and a solid basis for more comprehensive estimates of biomass availability while address other environmental issues such as erosion control and soil C.

Conclusions

The data provided by the local conservation districts in Indiana, the Century simulations, and the resulting public outreach support the following seven conclusions:

1. Indiana cropland soils are shown as a C sink prior to 1990 and continuing to sequester C over time. These soils in 1999 are removing 0.77 MMTC (~2.8 MMT of CO_2) from the atmosphere mainly through the adoption of conservation practices.
2. Mineral soils being cropped in Indiana are estimated to be sequestering 1.46 MMTC (~5.4 MMT of CO_2) in 1999, but the cultivation of organic soils are a source of 0.68 MMTC (~2.5 MMT of CO_2) back to the atmosphere in 1999.
3. Using results from this study, local land managers, working with local conservation planners have the ability to estimate rates of soil C change (C sequestration) depending on the types of management decisions that are implemented.
4. The CSRA provides a tool to help gather local land use data.
5. Indiana Conservation Districts are willing to report to the U.S. DOE, through the use of the EIA-1605 (b) reporting procedures, the C sequestered by the implementation of conservation practices.
6. The Indiana Conservation Partnership, including local conservation districts, state agencies, and NRCS, were willing to take a leadership role, along with the support of NACD, aimed at increasing awareness of the C sequestration issue, and the role of agriculture.
7. 100% of the Indiana Conservation Districts were willing to participate in research dealing with C sequestration and to provide the valuable local information that is necessary to enhance C simulation computer modeling.

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- Indiana Conservation Districts for providing local data knowledge, and
- National Association of Conservation Districts for providing project management at the national level and for coordinating with the districts and state partners to complete data collection and carry out an information and education program.

Appendix A: CSRA Data Sheets

Current Land Use Information

CARBON SEQUESTRATION RURAL APPRAISAL

CURRENT LAND USE INFORMATION FROM LOCAL KNOWLEDGE (SHEET A)

STATE INDIANA **COUNTY** ______

FOR INDICATED SOILS ON MAP DETERMINE:

MUID (STATSGO ASSOCIATION)								
LAND USE INFORMATION								
TOTAL CROPLAND								
CLASS I & II								
CLASS III & IV								
CLASS V & VI								
BOTTOMLAND/HARDWOODS								
FOREST OR TREES								
GRASS LANDS								
WATER / WETLANDS								
URBAN / OTHER								
TOTAL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
LANDSCAPE DESCRIPTION								
FLAT (<2% SLOPE)								
ROLLING HILLS (2-6% SLOPE)								
STEEP HILLS (>6% SLOPE)								
FLOOD PLAIN								
OTHER								
TOTAL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

TOTAL CROPLAND: % OF THIS SOIL IDENTIFIED AS CROPLAND . THE SUM OF LAND CAPABILITY CLASS I & II, III & IV, AND V & VI MUST ADD TO THIS %.

CLASS I & II: % OF THIS SOIL THAT IS CLASS I & II CROPLAND.

CLASS III & IV: % OF THIS SOIL THAT IS CLASS III & IV CROPLAND.

CLASS V & VI: % OF THIS SOIL THAT IS CLASS V & VI CROPLAND.

BOTTOMLAND/HARDWOODS: % OF THIS SOIL IDENTIFIED AS BOTTOMLAND/HARDWOODS BUT NOT INCLUDING FOREST OR TREES.

FOREST OR TREES: % OF THIS SOIL IDENTIFIED AS FOREST OR TREES BUT NOT INCLUDING BOTTOMLAND HARDWOODS.

GRASS LANDS: % OF THIS SOIL IDENTIFIED AS GRASS LANDS.

WATER / WETLANDS: % OF THIS SOIL IDENTIFIED AS WETLANDS.

URBAN / OTHER LANDS: % OF THIS SOIL IDENTIFIED AS OTHER LANDS INCLUDING URBAN LANDS, DEVELOPED LANDS, ABANDONED LANDS.

LANDSCAPE DESCRIPTION: % OF THIS SOIL IN EACH LANDSCAPE DESCRIPTION.

Drainage Information

CARBON SEQUESTRATION RURAL APPRAISAL

GENERAL LAND USE INFORMATION FROM LOCAL KNOWLEDGE (SHEET B)

STATE INDIANA ____________ **COUNTY** ____________________

HAS ANY PART OF THE COUNTY BEEN DRAINED (YES/NO): __________
IF YES, ANSWER THE FOLLOWING.

	OPEN DITCH DRAINAGE		TILE DRAINAGE	
MUID	TIME PERIOD OF INSTALLATION	% OF SOIL DRAINED	TIME PERIOD OF INSTALLATION	% OF SOIL DRAINED

MUID: SOIL MAP UNIT ID FROM STATSGO. (FROM MAP)
TIME PERIOD OF INSTALLATION: GIVE THE TIME PERIOD WHEN DRAINAGE PRACTICES WERE INSTALLLED. (i.e. 1930-1950, 1940-1960, 1970-1990, ETC.)

% OF SOIL DRAINED: GIVE AN ESTIMATE FOR THESE SOILS OF THE AMOUNT OF DRIANAGE INSTALLED.

Irrigation Information

CARBON SEQUESTRATION RURAL APPRAISAL

GENERAL LAND USE INFORMATION FROM LOCAL KNOWLEDGE (SHEET C)

STATE INDIANA __________ **COUNTY** ____________________

IS 10% OR MORE OF ANY MUID IRRIGATED (YES/NO): ____________

IF YES, ANSWER THE FOLLOWING.

MUID	TIME PERIOD OF INSTALLATION	% OF SOIL IRRIGATED	ANNUAL AMOUNT APPLIED (INCHES)	TYPES OF SYSTEMS

MUID: SOIL MAP UNIT ID FROM STATSGO. (FROM MAP)
TIME PERIOD OF INSTALLATION: GIVE THE TIME PERIOD WHEN IRRIGATION PRACTICES WERE INSTALLLED. (i.e. 1930-1950, 1940-1960, 1970-1990, ETC.)

% OF SOIL IRRIGATED: GIVE AN ESTIMATE FOR THESE SOILS OF THE AMOUNT OF IRRIGATION INSTALLED.
ANNUAL AMOUNT APPLIED (INCHES): GIVE AN ESTIMATE OF THE ANNUAL AMOUNT OF IRRIGATION WATER APPLIED IN INCHES. (6 INCHES, 12 INCHES, 15 INCHES, ETC.)

TYPES OF SYSTEMS: TYPICAL TYPE OF IRRIGATION SYSTEM INSTALLED. (CENTER PIVOT, GATED PIPE, ETC.)

Cropping And Management Information

CARBON SEQUESTRATION RURAL APPRAISAL

COUNTY LEVEL FARMING AND CROPPING SYSTEM HISTORY FROM PRE 1900 TO PRESENT (SHEET D)

STATE INDIANA ____________ **COUNTY** ____________________

TIME FRAME __________

% ESTIMATE OF COUNTY BEING FARMED DURING THIS TIME FRAME: __________

CROP ROTATIONS (SPECIFY 1 TO 3)

1) ______________________________

2) ______________________________

3) ______________________________

FOR INDICATED CROPS

CROP NAME					
YIELD (BU OR TONS/AC)					
N FERT APPLIED (LBS/AC)					
MANURE APPLIED (TONS/AC)					
TYPICAL TILLAGE OPERATIONS					

Comments: ______________________________

____

TIME FRAME: PERIOD OF TIME AS SPECIFIED.
% ESTIMATE OF COUNTY BEING FARMED DURING THIS TIME FRAME: GIVE AN ESTIMATE OF THE COUNTY AREA BEING FARMED DURING THIS TIME FRAME.
TYPICAL CROP ROTATION: CROP ROTATIONS INCLUDE (CORN-CORN; CORN-SOYBEAN; CORN-CORN-OATS-MEADOW-MEADOW; CORN-SOYBEAN-CORN-OATS-MEADOW-MEADOW; ETC)
FOR INDICATED CROPS: ACTUAL CROP INFORMATION FOR THE INDICATED CROPS IN THE ROTATIONS.
CROP: CROP NAME AS SHOWN IN CROP ROTATION.
YIELD: CROP YIELD IN BU/AC FOR GRAINS OR TONS/AC FOR HAY.
N FERT APPLIED: ESTIMATE OF COMMERCIAL NITROGEN FERTILIZER APPLIED ANNUALLY (LBS/AC).
MANURE APPLIED: ESTIMATE OF MANURE APPLIED ANNUALLY (TONS/AC), BY CROP.
TYPICAL TILLAGE OPERATIONS: TYPICAL TILLAGE OPERATIONS USED TO GROW THIS CROP. (EXAMPLES ARE FALL PLOW; SPRING PLOW; CHIESEL PLOW; DISK; HARROW; CULTIVATOR; DRILL; PLANT; ETC.)

Annual Conservation Practice Installed

ANNUAL CONSERVATION PRACTICES INSTALLED

PRACTICES INSTALLED BY COUNTY AND SOIL TYPE

USE IN REPORTING TO DOE FOR CARBON SEQUESTRATION
(USE SEPARATE SHEET FOR EACH SOIL MUID)

STATE INDIANA ______ **COUNTY** ______ **MUID** ______

	ACRES OF CONSERVATION PRACTICES INSTALLED (ACRES)						
	COMMON CROP ROTATION (s)				GRASS CONVERSIONS	TREE PLANTING	WETLANDS CREATED AND/OR RESTORED
	ROTATION NO-TILL	NO-TILL	ROTATION NO-TILL	NO-TILL			
1985							
1986							
1987							
1988							
1989							
1990							
1991							
1992							
1993							
1994							
1995							
1996							
1997							
1998							
1999							
2000							

MUID: SOIL MAP UNIT ID FROM STATSGO. (FROM MAP)

CROP ROTATION: PICK THE TWO MOST COMMON CROP ROTATIONS. IF ONE ROTATION IS >90% OF CROPPED ACRES, REPORT ONLY THAT ROTATION. REFER TO THE CTIC REPORTED VALUES FROM 1989 TO PRESENT.

ROTATIONAL TILLAGE: INCLUDES ALL TILLAGE SYSTEMS THAT LEAVES > 15% CROP RESIDUE COVER FOR THE ROTATION. THIS INCLUDES MINIMUM TILLAGE ON CORN OR WHEAT AND NO-TILL SOYBEANS. IT IS THE CROP ROTATION SYSTEM THAT IS BEING EVALUATED, NOT A SINGLE YEAR.

NO-TILL: NO-TILL FARMING SYSTEM WITH NO DISTURBANCE OF THE SOIL SURFACE OTHER THAN OPERATIONS FOR INJECTION OF NITROGEN AND PLANTING OF CROPS.

GRASS CONVERSIONS: ALL GRASS PLANTING CONSERVATION PRACTICES.
(WATERWAYS, BUFFERS INCLUDING RIPIARIAN BUFFERS, FILTER STRIPS, TERRACES, CRP).
USE 12' WIDTH FOR TERRACES (LF*12/43560=ACRE).
USE 40' WIDTH FOR ALL OTHER PRACTICES REPORTED IN LINEAR FEET (LF*40/43560=ACRE).

TREE PLANTING: ALL CONSERVATION PRACTICES THAT INCLUDE TREE PLANTINGS. (WINDBREAKS, SHELTERBELTS, AGRO-FORESTRY)

WETLANDS CREATED AND/OR RESTORED: ALL CONSERVATION PRACTICES THAT INCLUDE THE CREATION OR RESTORATION OF WETLANDS.

Appendix B: County Drainage Dates

County	Early Drain	Late Drain
Adams	1905	1960
Allen	1909	1965
Bartholomew	1917	1952
Benton	1920	1948
Blackford	1905	1965
Boone	1905	1945
Brown	1925	1965
Carroll	1908	1945
Cass	1905	1945
Clark	1930	1956
Clay	1909	1969
Clinton	1905	1945
Crawford	1914	1955
Daviess	1934	1967
De Kalb	1905	1945
Dearborn	1920	1960
Decatur	1923	1950
Delaware	1905	1950
Dubois	1922	1968
Elkhart	1911	1949
Fayette	1940	1970
Floyd	1914	1955
Fountain	1905	1956
Franklin	1905	1969
Fulton	1905	1945
Gibson	1923	1964
Grant	1906	1945
Greene	1903	1954
Hamilton	1905	1945
Hancock	1905	1945
Harrison	1925	1945
Hendricks	1905	1960
Henry	1905	1945
Howard	1907	1945
Huntington	1905	1960
Jackson	1911	1966
Jasper	1929	1950
Jay	1925	1945
Jefferson	1944	1970
Jennings	1923	1963
Johnson	1905	1945
Knox	1916	1953
Kosciusko	1923	1954
La Porte	1910	1950
Lagrange	1909	1955
Lake	1910	1945

County	Early Drain	Late Drain
Lawrence	1932	1965
Madison	1916	1945
Marion	1905	1960
Marshall	1923	1970
Martin	1925	1960
Miami	1905	1945
Monroe	1905	1960
Montgomery	1918	1968
Morgan	1901	1964
Newton	1910	1963
Noble	1910	1945
Ohio	1925	1960
Orange	1925	1963
Owen	1914	1958
Parke	1903	1960
Perry	1920	1960
Pike	1920	1949
Porter	1923	1945
Posey	1911	1946
Pulaski	1900	1945
Putnam	1918	1969
Randolph	1905	1945
Ripley	1930	1965
Rush	1913	1944
St Joseph	1914	1956
Scott	1925	1945
Shelby	1900	1952
Spencer	1919	1950
Starke	1920	1958
Steuben	1906	1949
Sullivan	1928	1962
Switzerland	1935	1970
Tippecanoe	1907	1946
Tipton	1905	1957
Union	1925	1969
Vanderburgh	1925	1970
Vermillion	1905	1948
Vigo	1906	1957
Wabash	1903	1947
Warren	1908	1953
Warrick	1923	1970
Washington	1931	1958
Wayne	1914	1956
Wells	1925	1958
White	1905	1945
Whitley	1905	1945

Appendix C: 1990-1999 Indiana C budget spreadsheet user instructions

The following section is intended as an overview of the basic hardware and software requirements for this spreadsheet application.

System Requirements

In order to run this spreadsheet application, you will need a computer system that meets the following requirements:

- Microsoft Windows 95, 98, NT version 4.0, Windows 2000 or Windows XP
- Recommended Pentium, Pentium II, or Pentium III class computer
- A minimum of 2 MB of hard drive space

Please note that if your system meets the requirements as described in Appendix D. this application will function fine.

Software Requirements

The spreadsheet was written in Microsoft Excel 97 and Microsoft Excel 2000.

Installation Of The Spreadsheet

The CD contains files capable of running on machines using operating systems Windows 95, Windows 98, Windows 2000, Windows NT 4.0 or Windows XP.

- 1990-1999IndianaCarbonBudget.xls: This is the spreadsheet that runs on Microsoft Excel, which is distributed with Microsoft Office 97 or Microsoft Office 2000

To copy the spreadsheet to your hard drive, follow these steps:

1. Insert the CD containing the spreadsheet into your CD-ROM device.
2. Open the windows explorer and click on the CD-ROM icon in the "folders" window on the left side of the screen.
3. Locate the spreadsheet and click once on the file to highlight it. Click on the "Edit" menu bar on the upper left corner of the screen, and then click on the "copy" option.
4. Locate the hard drive folder to which you wish to copy the spreadsheet. Click once on that folder to highlight it. Click on the "Edit" menu bar again, and then click on the "paste" option.

This should have copied the files to your local drive. Depending on the speed of your PC, it could take a few seconds to copy the files. In order to run the spreadsheet, first open Microsoft Excel. Select the "File" menu bar in the upper left corner, and then click on the "open" option.

An “Open File” dialog box will open in the center of the screen. Find the hard drive and file folder to which you copied the spreadsheet, and select the file. Then click the “Open” button on the right side. Once the file is open, proceed to the next section for instructions how to use the spreadsheet.

Operating Instructions And Example

The spreadsheet utilizes a pull down menu located in cell B1. To activate the menu, click on cell B1 and a list of all the counties in Indiana will appear, a list of regions as documented in the Phase I part of this report and a state total option. The regions are identified using an additional character ‘Z’ and state totals are identified using an additional two characters ‘ZZ’. In order to extract county data from the spreadsheet, the user must specify an option from the pull down menu. Once an option is selected, three graphs will appear which provide information on:

- C changes in mineral soils from 1990-1999 for intensive, moderate and no tillage systems, grass conversions and tree/wetland conversions
- Associated acres of intensive, moderate and no tillage systems, grass conversions, tree/wetland conversions and cultivated organic soils
- C budget including mineral and organic soils

These individual sets of data will allow land managers to compare issues across counties, regions and the state.

Appendix D: Indiana CarbOn Management Evaluation Tool (COMET) Database User Instructions

Installation and Use Instructions For The 'Indiana CarbOn Management Evaluation Tool (COMET)' Database

February, 2002

A cooperative effort between the Colorado State University, Natural Resource Ecology Laboratory and USDA-Natural Resources Conservation Service

Fort Collins, CO 80523

Introduction

The following section is intended as an overview of the basic hardware and software requirements for the Indiana COMET database. We also try to provide a basic understanding of what kind of performance you can expect from your computer when running the database. Detailed installation instructions are provided in the next section.

System Requirements

In order to run this database, you will need a computer system that meets the following requirements:

- Microsoft Windows 95, 98, NT version 4.0, Windows 2000 or Windows XP
- Pentium II, or Pentium III class computer
- A minimum of 32 MB of RAM
- A minimum of 750 MB of hard drive space

Please note that if you are using virtual memory on your hard drive (which usually uses about 120 MB of hard drive space), then you will need 750 MB of additional hard drive space above and beyond what your minimum virtual memory settings require

Screen Size Limitations

The database is optimized to run with a screen size of at least 1152 x 864 pixels. You can use the database on screens having a smaller pixel resolution, however you may need to use the scroll bars on the right side and bottom of the screen to view the data. For information on how to change your screen size, look up "To change the size of the screen area" under your Windows operating system help.

Software Requirements

The database was written in Microsoft Access 97 and compiled for either Microsoft Access 97 or Microsoft Access 2000. We've provided separate files for either version, and installation instructions are provided for either version later in this document.

If you use Access 97, we strongly recommend that you install the Office 97 service release 2b or higher. For more information on how to download/receive by mail and install this service release, see the Microsoft web site: <http://officeupdate.microsoft.com/Articles/sr2fact.htm>

If you use Access 2000, we also strongly recommend that you install Office 2000 service release 1a or higher. For more information on how to download/receive by mail and install this

service release, see the following Microsoft web site:
<http://officeupdate.microsoft.com/2000/downloadDetails/O2kSR1DDL.htm>

Performance Expectations

This database provides output by searching a large data table for the values that meet the county, soil type, and cropping history criteria selected by the user. This table and the queries that access these data are optimized for maximum performance. Query speed and performance limitations that you may experience will be due to limitations in processor speed, available cache memory, or RAM capacity and speed.

The database was developed on a one year-old desktop, running a Pentium III processor with 212 MB of RAM, 512K cache, operating at 1.6 GHz. It takes less than 3 seconds to open the database on this machine. It takes approximately 2 seconds to complete the very first query that is conducted in each session, and less than 2 seconds for all subsequent queries. These tests were conducted with no other software programs running. We saw substantial performance improvements when running the database on machines with faster processors. Increasing RAM memory above 128 MB did not improve performance substantially, whereas decreasing memory to below 32 MB did hamper performance very significantly. On machines that have at least 128 MB of RAM installed, users can roughly expect the query times to be inversely proportional to the speed of the processor being used. For example, a Pentium III class machine with 128 MB of RAM and a processor running at 733 MHz will access and display the data in about ½ of the time required by the Pentium II at 400 MHz. In a similar vein, running the database on machines with Celeron Processors can result in decreased performance, since the Celeron lacks cache memory and has less processing power. We wish to advise users that running the database on older Pentium-class machines can be frustrating.

Some Tips On Running Microsoft Access

This database program was written and compiled using standard dynamic link libraries provided by Microsoft with Access 97, 2000, and the Visual Studio Development Environment. There are no user-defined or custom libraries used. It will not overwrite any system or locally defined libraries.

We have found, particularly with Office 97, that running applications in a multitasking environment can impede performance of this database. If you wish to maximize the performance of this database, we recommend you close most or all other concurrently running programs.

We have also found that Microsoft Access 97 and Access 2000 can be somewhat "buggy" when you run them in a multitasking environment. This is particularly true when running them with Netscape Communicator and/or Microsoft Internet Explorer open. Users may experience infrequent or seemingly random program crashes, during which Access abruptly warns the user of an operating system error and then closes the program. If you experience this only occasionally, we believe you should try to live with the system crashes. If this happens repeatedly or under circumstances that you can repeat, then you should consider seeking assistance from your system administrator or from Microsoft.

Installation Of The Database

The two CD's contain files capable of running on machines using operating systems Windows 95, Windows 98, Windows 2000, Windows NT 4.0 and Windows XP. One CD contains the 'Indiana_COMET_97.mde' database, the 'user_instructions.ppt' presentation, the '1990-1999IndianaCarbonBudget.xls' spreadsheets and the 'Indiana_Final_Report.pdf'. The other CD contains the 'Indiana_COMET_2000.mde' database, the 'user_instructions.ppt' presentation, the '1990-1999IndianaCarbonBudget.xls' spreadsheets and the 'Indiana_Final_Report.pdf'.

- Indiana_COMET_97.mde: This is the database version that runs on Microsoft Access, version 7.0 (also called Access 97), which is distributed with Microsoft Office 97
- Indiana_COMET_2000.mde: This version runs with Microsoft Access 2000, which is distributed with Microsoft Office 2000
- user_instructions.ppt: This file is a Microsoft PowerPoint presentation which provides step by step procedures necessary to use the Indiana COMET database
- Indiana_Installation_and_Use.doc: This is a Microsoft Word document which provides the step-by-step procedures for use of the Indiana COMET database
- 1990-1999IndianaCarbonBudget.xls: This file summaries the C sequestration results by county, by region and for the entire state
- Indiana_Final_Report.pdf: This file is a Adobe Acrobat file that can be read using Adobe Acrobat Reader and is the final report to the Indiana Conservation Partnership.

IMPORTANT NOTE!
THE DATABASE WILL NOT RUN DIRECTLY OFF OF THE CD.
TO RUN THE DATABASE, YOU MUST COPY THE FILE FROM THE CD TO YOUR HARD DRIVE.

In order to run the database, you **must** copy the database version that you wish to use off of the CD and onto your hard drive. This is necessary because Microsoft Access will try to make changes to the file each time you open the database. If it cannot do so (which will be the case on a CD-ROM, since it is a read-only device), it will report an error and fail to open the database.

To copy the database to your hard drive, follow these steps:

1. First create a new folder titled "Indianacomet" on your C:\ drive using windows explorer.
2. Insert the CD containing the database into your CD-ROM device.
3. Open the windows explorer and click on the CD-ROM icon in the "folders" window on the left side of the screen.
4. Locate the database (97 or 2000) you wish to copy. Click once on the file to highlight it. Click on the "Edit" menu bar on the upper left corner of the screen, and then click on the "copy" option.
5. Locate the new folder 'Indianacomet' directory on the c:\ drive (created in 1 above). Click once on that folder to highlight it. Click on the "Edit" menu bar again, and then click on the "paste" option.
5. Repeat steps 3-5 above to copy the (user_instructions.ppt) power point file to the c:\Indianacomet\ directory on your hard drive. (Note: This has to be done so the tutorial will function properly).
6. Repeat steps 3-5 above to copy the (Indiana_Installation_and_Use.doc) word file, the (1990-1999IndianaCarbonBudget.xls) spreadsheets and the (Indiana_Final_Report.pdf) final report to your hard drive.

This should have copied the files to your local drive. Depending on the speed of your PC, it could take from a few seconds to several minutes to copy the files. In order to run the database, first open Microsoft Access. Select the "File" menu bar in the upper left corner, and then click on the "open" option. An "Open File" dialog box will open in the center of the screen. Find the c:\Indianacomet\ directory and select the database file. Then click the "Open" button on the right side. The database file will probably take from 5-20 seconds to open, depending on the performance of your machine. Proceed to the next section for instructions how to use the database.

The tutorial 'user_instructions.ppt' can be viewed directly from the database by clicking the 'Tutorial' button on the main screen. The tutorial should be reviewed prior to using the database.

Operating Instructions And Example

In order to extract data from the database, the user must specify the following input parameters:

- County
- History
- Soil surface texture (e.g. SICL = silty clay loam, SL = sandy loam, etc.)
- Soil hydric condition (yes or no)
- Management History

The first three items are fairly self-explanatory. The user specifies the management history by defining crop rotation and tillage method for twenty-year increments (1974-1994, 1995-2014) in two scenarios. By specifying two scenarios, the operator is able to compare carbon sequestration potential in two different management regimes.

The following procedure explains how to use the database. Assume that the user wants to compare growing a intensive tilled corn-soybean rotation with a no tillage system for the same rotation, on a non hydric silt loam in Adams County, Indiana. The power point presentation 'user instructions' provides a step by step procedure on how to use the database.

The user first specifies the county of interest in the **County** field.

Use the mouse to click on the **History** field and select one that closely matches the 1950-1974 time period.

Use the mouse to click on the downward-pointing arrow in the **Surface Texture** box. This presents a list of the most common surface textures found in the county selected, based on information in the STATSGO database. Note that the database will not allow a user to specify a soil texture until a county is specified. The codes refer to the following surface textures:

- CL (clay loam)
- L (loam)
- LS (loamy sand)
- S (sand)

- SIC (silty clay)
- SICL (silty clay loam)
- SIL (silt loam)
- SL (sandy loam)

The user then specifies whether the soil is hydric or not (Yes or No) in the **hydric?** field. Note that we have specified hydric condition according to information in the STATSGO database.

Use the mouse to click on the downward-pointing arrow in the **Reference Management System** field. This presents a list of crop systems common to the area and the user must select one.

Under **Management System A**, **rotation 1**, 1974-1994, specify the rotation desired.

- bean-corn 20 yrs

Under **Management System A**, **method 1**, specify the tillage method. The codes correspond to the following:

- intensive tillage - multiple tillage operations every year
- moderate tillage - spring disk, harrow and planting, also included every other year tillage as in corn-bean rotation where the beans are planted into the corn residue and strip tillage
- no tillage – no tillage operations except to inject N and to plant

Note that the method available in the database is limited in some cases. For example, all rotations that have CRP included are limited to intensive tillage prior to conversion to CRP and no tillage after the CRP conversion.

Specify **rotation 2** and **method 2** as done above. Note that the options for the second rotation are slightly different. The rotations are offered in 20 year blocks only, with CRP offered as a separate block.

Repeat steps for **Management System B**.

When these data are entered into the fields as described above, the **Show Data** button will become active. Clicking on that button will execute a query that extracts the data requested from the database. It will then show the data in graphic format (one graph for each scenario). The differences between the two scenarios are shown in tabular format.

Clicking on the **View Data Table** button brings up the database table that contains the data from the model runs. You can copy and paste data as needed from this table. Clicking on the **Reset** button clears the data input fields and sends the cursor back to the **County** field to start over.

Interpreting The Graphs

Note that the graphs have several data lines. Units are specified in metric tonnes/hectare (1 hectare = 2.47 acres). The red line shows the reference management system that was selected. The green line shows the carbon levels in the soil + residue category under the management scenario specified. The blue line shows soil carbon levels without residues included.

Change Read-Only Attributes Of Files After Copying To Your Hard Drive

When installing the database and tutorial program from CD to your hard drive, users will need to change the attributes of the files so that they are no longer read-only. Files that are written to CD's are typically made read-only, and the file remains Read-Only when it is copied back to a hard drive. Following are instructions on how to change the read-only attributes of the files copied to your hard drive, so the database and tutorial will run:

- With "Windows Explorer" or the "My Computer" folder open, and after copying the files from the CD to the hard drive, click once on the Indiana_COMET_2000.mde so that it is highlighted
- With the file highlighted, click once on the "File" menu, and then click once on the "properties" option. In the window that opens, select the "General" tab and un-check the "Read-Only" box near the bottom of the window. You can un-check the box by clicking on it once
- Click once on the "Accept" button to finalize the change, and then click once on the "OK" button to close the window
- Repeat step above for the other files on the CD

Tutorial Sometimes Fails To Load

We have found that on some machines, the tutorial fails to load completely after clicking on the "Tutorial" button on the upper right corner of the screen. The software is written to open the 'user_instructions.ppt' file automatically and load the tutorial presentation. We acknowledge that this is a bug in the software and we are preparing a solution for future distributions of the database. If this problem occurs on your computer, use the following simple workaround to allow you to view the tutorial:

- With PowerPoint open, click once on the "File" menu. Then click once on the "Open" option
- In the "Open" window that appears on the screen, locate the file 'user_instructions.ppt' on

your hard drive. Click once on the file to highlight it and then click once on the “Open” button in the lower right corner of the window

- After viewing the tutorial, close PowerPoint by selecting the “Exit” option from the “File” menu. The operating system should return directly to the database

Troubleshooting

User errors generally arise from not understanding the assumptions and limitations placed upon the model used to generate the data. We have found in the initial testing that many users tried to specify rotations or soil types that did not exist in the database. Keep in mind that we limited the number of soil types and crop rotations used in the model to those most commonly found. Those not found in the list were left out of the model run for reasons of simplicity and manageability.

We wish to know about software bugs that arise, and to receive feedback from users about rotations, tillage practices, and soil textures that we should consider modeling for the database. Please report these items by e-mail to:

Mark Easter
Natural Resource Ecology Laboratory, NESB-B252
Colorado State University
Fort Collins, CO 80523
mark.easter@colostate.edu
(970) 491-7662 VOICE
(970) 491-1965 FAX

In your feedback, it is necessary that you provide the following information:

- Operating system (Win95, Win98, Win2000, NT4.0 XP)
- Version of Access (7.0/97, 2000, 2001 or XP)
- A complete description of the bug including examples
- Please avoid using jargon
- The circumstances that lead to the bug or error condition
- An exact description of the error code and text that appears

Appendix E: Public Outreach

General Public Distribution

National

- Indiana Carbon Storage Project Going Strong. National Association of Conservation District news & views, July/August 2000
- Global Climate Change Emerging Issue of a New Century – National Association of Conservation District publication
- USDA Global Change Fact Sheet Soil Carbon Sequestration: Frequently Asked Questions, December 2000

Regional

- Utilities hope 'less till' plan will reduce global warming – The Indianapolis Star – Business / March 22, 2000
- Agriculture and environment: growing carbon for climate change – ECOS The environmental communiqué of the states, A publication of The Council of State Governments, Vol. 7, No 4

State

- IASCD Report Card March 2000
- Conservation Practices May Help Meet Climate Control Challenge – Marion County SWCD March 2000 Newsletter
- Farmers may hit pay dirt by growing cleaner air – The Daily Ledger April 19, 2000
- Carbon credit trading helps mitigate carbon dioxide effects – The Dearborn County Register June 1, 2000
- Cutting Edge Scientific Research Conducted Locally – NRCS media release March, 2000
- Carbon Sequestration Could Lead to Benefits for Conservation & Agriculture – Nonpoint Notes, April, 2000
- Possible Solutions for Greenhouse Effect – Harrison County SWCD Newsletter, September, 2000
- Growing Carbon for Climate Change – State Trends, Fall 2000 V.6, I.4
- Carbon sequestration benefits air, soil and water quality – Indiana Agrinews, January 26, 2001

- Carbon Storage – Henry County SWCD Newsletter, April, 2000
- Carbon Storage – A New Crop – Floyd County SWCD Newsletter, April 2000
- Local farmers may soon be producing an unknown crop – Hendricks County Flyer, April 6, 2000

Meeting/Conference Presentation

Year	Meeting/Conference	Location	Audience
1999	NRCS State Partnership Meeting	Indianapolis, IN	State
1999	NRCS State Partnership Meeting	Lincoln, NE	State
1999	OK Association of Conservation Districts	Oklahoma City, OK	State
2000	Nebraska Association of NRD's Annual Meeting	Lincoln, NE	State
2000	Seminar for EPA Regional Office	Denver, CO	Regional
2000	Global Sustainability Conference: Progress Through Research	Springfield, IL	National
2000	CARBON: Exploring the Benefits to Farmers and Society	Des Moines, IA	National
2001	Indiana Association of Conservation Districts Annual Conference	Indianapolis, IN	State
2001	NRCS State Partnership Meeting	Indianapolis, IN	State
2001	NRCS State Partnership Meeting	Fresno, CA	State
2001	CO Association of Conservation Districts	Fort Collins, CO	State
2001	National Wheat Growers Association Annual Meeting	New Orleans, LA	National
2001	USDA Ag Outlook Forum	Washington, DC	National
2001	Soil & Water Conservation Society International Meeting	Myrtle Beach, SC	International
2001	9th U.S.-Japan Workshop on Global Climate Change	Tokyo, Japan	International
2001	EU workshop on Carbon Sequestration in European Grasslands	Foulum, Denmark	International
2002	USDA Ag Outlook Forum	Washington, DC	National